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How Preservice Elementary Teachers' Design and Facilitation of a Maker Faire Activity Contributes to Differences in Children's Learning

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How Preservice Elementary Teachers’ Design and Facilitation of a Maker Faire Activity Contributes to Differences in Children’s Learning

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in Education

by

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ABSTRACT

How Preservice Elementary Teachers' Design and Facilitation of a Maker Faire Activity Contributes to Differences in Children's Learning

by

Alexandria Killian Hansen

Science education is changing. With the release of the *Next Generation Science Standards* [*NGSS*], K-12 teachers are expected to engage students in the practices of scientists and engineers to make sense of disciplinary core ideas and crosscutting concepts (NGSS Lead States, 2013). Simultaneously, there is a push to expose students to Science, Technology, Engineering, and Mathematics (STEM) in an integrated manner (Honey, Pearson & Schweingruber, 2014). The Maker Movement is one initiative that has received attention for its potential to transform STEM learning (Vossoughi & Bevan, 2014). This movement has spurred the creation of *educative making* as a pedagogical approach to engage students in integrated STEM learning experiences while still meeting the *NGSS*' performance expectations (Bevan, 2017). Currently, scant research exists on how to prepare teachers to facilitate these types of learning experiences in ways that result in rich learning experiences, especially at the preservice level. This study aims to close that gap.

I investigated how the design and facilitation of two science activities at a Maker Faire impacted opportunities for children's learning. The activities were designed and facilitated by preservice elementary school teachers enrolled in a university Science Methods course as part of their requirements to earn a Multiple Subjects (Elementary School) Teaching Credential and Master of Education in Teaching degree (M.Ed.). Preservice

teachers worked in small groups to design and facilitate their *NGSS*-aligned activity as the culminating assignment for their Science Methods course. The primary audience for the event was elementary school students enrolled in the preservice teachers' student-teaching classrooms. Using a case study model, I focused attention on two preservice teachers who worked in different groups, Ms. Sarah and Ms. Maggie. Ms. Sarah and her group members' station featured a slime making activity for children to learn about different states of matter. Ms. Maggie and her group members' station provided opportunities for children to tinker with various materials to develop models of magnetism.

Using previous frameworks (e.g., Bevan, Ryoo, Vanderwerff, Wilkinson & Petrich, 2017), I analyzed the design of activity, facilitation, and resulting indicators of children's learning through detailed video analysis (Erickson, 2006). The slime station was designed to resemble a factory line, requiring all children to work through the same set of pre-defined steps to create the teacher's anticipated version of slime. This resulted in Ms. Sarah and her group members emphasizing procedures, providing more direct instruction and asking more close-ended questions. This, in turn, caused children to frequently ask questions to ensure they were following the correct procedures specified by the teachers. In contrast, the magnetism station featured a series of smaller activities, differentiated to allow for multiple pathways based on each child. Ms. Maggie and her group members asked more open-ended questions, used less direct instruction, encouraged risk-taking and experimentation, engaged with observations more often, and frequently changed their instruction based on children's ideas. This resulted in children demonstrating higher instances of conceptual understanding than was observed at the slime station. Moreover, children who visited the magnetism station showed significantly more indicators of learning than children who visited the slime

station, $t(22) = 2.5$, $p = .019$. Implications for educators and teacher educators are shared in the discussion, as well as future directions for research.

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Teaching is a complex profession, requiring teachers to operate in dynamic, ill-structured environments (Putnam & Borko, 2000). At any given moment, a teacher is forced to make decisions—decisions such as how to best introduce a new concept in an engaging manner, how to ensure that concept is accessible to all students, how to facilitate group discussions, or how to manage student behavior once an activity begins. Jackson (1974) referred to this issue as the "problem of complexity" (p. 161). Considering the complexities awaiting teachers in diverse classrooms, the work of teacher educators is crucial and challenging.

Teacher education is further complicated by two problems: 1) the apprenticeship of observation, and 2) the problem of enactment. The apprenticeship of observation refers to the idea that, because almost everyone has experienced a classroom from the perspective of a student, they often have preconceived ideas about effective (and ineffective) teaching, which may or may not be supported by research (Lortie, 1975). This suggests that teacher educators often need to help preservice teachers develop more nuanced understandings of how people learn (Darling-Hammond & Bransford, 2007). This is further agitated by the problem of enactment (Kennedy, 1999). Even if a teacher understands research-based theories of learning, she still might struggle to enact those principles when working with students.

In the context of teacher education for *elementary school teachers*, other problems arise. Elementary school teachers are often required to teach every subject to all their students. While some universities allow undergraduates to major in education and gain familiarity with content and pedagogical approaches in multiple disciplines, many reserve Teacher Education for post-baccalaureate programs. In California, for example, individuals interested in earning a Teaching Credential usually complete an undergraduate degree *before* applying to a Teacher Education program. Additionally, it is more common for elementary school teachers to hold undergraduate degrees in the liberal arts (e.g., Sociology, History, English) than degrees in the sciences (California Council on Science and Technology, 2010); this furthers the problem of enactment. If a teacher does not have a deep foundation of content knowledge about a discipline, it is difficult to effectively teach that subject (Hammerness et al., 2005). *Science teacher educators* are in a unique position to investigate what types of preservice learning experiences are most useful in preparing future elementary school teachers to effectively engage students in science learning.

To further complicate elementary teacher education related to science, standards have recently changed. Guided by *A Framework for K-12 Science Education* [*Framework*] (National Research Council [NRC], 2012), the *Next Generation Science Standards (NGSS)* represent a significant shift in how teachers are asked to engage their students in learning science and, for the first time at a national level, engineering. Rather than emphasizing factual recall and procedural information, the *NGSS* challenges teachers to support students in learning science through engaging in the *practices* of scientists and engineers, practices such as asking questions (for science) and defining problems (for engineering). Students should engage in the practices of scientists and engineers to construct their own understandings of disciplinary content, aided by the identification of crosscutting themes, such as patterns or scale, which transcend individual STEM disciplines (NRC, 2012).

Simultaneously, there is a push to expose students to Science, Technology, Engineering, and Mathematics (STEM) in an integrated manner (Honey, Pearson & Schweingruber, 2014). In response, a wide array of pedagogical approaches, curricular programs and initiatives have emerged (Honey & Kanter, 2013). One recent trend receiving attention from informal and formal educators for its power to transform STEM education is the Maker Movement (Bevan, Gutwill, Petrich & Wilkinson, 2015; Blikstein, 2013; Halverson & Sheridan, 2014; Martin, 2015). This movement extols the design and fabrication of personally meaningful artifacts—using knowledge and skills from the disciplines of science, technology, engineering, art, and mathematics (STEAM) —for the purpose of sharing playful and useful creations with the world. The theoretical justification for this as an effective pedagogical approach to support learning exists in past scholarship, such as Dewey's (1902, 1938) focus on experiential learning, Papert's (1980, 1991) theory of constructionism, and Freire's (1970) notion of critical pedagogy (Blikstein & Worsley, 2016). Further, emergent research provides additional evidence for the benefits of making to learn (e.g., Peppler, Halverson & Kafai, 2016). Despite research documenting the benefits of making to learn, particularly for STEM disciplines, little research exists on how to prepare teachers to facilitate these types of learning experiences in ways that result in rich student learning, especially at the preservice level. This study aims to close that gap.

More specifically, in this study, I investigated how the design and facilitation of two activities in the context of a Maker Faire impacted opportunities for children's learning. These activities were designed and facilitated by preservice teachers enrolled in a post-baccalaureate Teacher Education Program in California, tasked with designing an *NGSS*-aligned activity for facilitation at a Maker Faire as part of their Science Methods coursework. Invited guests included the families of children enrolled in the preservice teachers' student-teaching classrooms.

Following a situated theory of learning (Brown, Collins, & Duguid, 1989; Greeno, 2006; Putnam & Borko, 2000), I conceptualized learning as the process of knowing, doing, and becoming (a scientist, engineer, effective teacher, etc.) by engaging in authentic practices situated in real-world contexts. I used previous frameworks (e.g., Bevan et al., 2017) to analyze the design of activity, facilitation techniques, and indicators of children's learning for two stations at the Maker Faire designed by preservice teacher candidates. One station was designed by Ms. Sarah[1] and three other preservice teachers for children to make slime and learn about different states of matter. The second station was designed by Ms. Maggie and two other preservice teachers for children to tinker with materials and learn about magnetism. The following, overarching question guided this study: *How does the design and facilitation of a Maker Faire activity contribute to differences in children's learning?* To address this larger question, the following research questions were answered:

1. How did Ms. Sarah design and facilitate the slime station at the Maker Faire?
2. What indicators of learning were observable among children who visited the slime station at the Maker Faire?
3. How did Ms. Maggie design and facilitate the magnetism station at the Maker Faire?
4. What indicators of learning were observable among children who visited the magnetism station at the Maker Faire?
5. How did the observable indicators of children's learning differ *by station*?
6. What salient factors of the station *design* and *facilitation* contributed to differences in children's learning?

The organization of this study is as follows. In Chapter 2, I review the literature to situate this study in the existing scholarship on the Maker Movement in K-12 education and teacher education. Chapter 3 presents the conceptual framework that guided this study, comprised of situated theories of learning and an overview of the frameworks used to analyze the design of activity, facilitation, and indicators of learning. In Chapter 4, the

[1] All names are pseudonyms.

research methodology and context for investigation are shared. Chapters 5 focuses attention on the slime station to answer the first two research questions. Chapter 6 focuses attention on the magnetism station to answer the third and fourth research questions. Chapter 7 answers the final two research questions—how did the observable indicators of learning differ by station, and what salient aspects of the design and facilitation contributed to differences in children's learning? Finally, Chapter 8 discusses the results and limitations of this study, implications for teachers and teacher educators, and future directions for research.

Chapter II. Literature Review

This study was grounded in the literature on educative making as a pedagogical approach to inspire Science, Technology, Engineering, and Mathematics (STEM) learning. In her substantive literature review, Bevan (2017) distinguished between three types of making discussed in current research: making as entrepreneurship, making as STEM workforce skill development, and educative making. Here, I focus on the latter category, *educative making*, defined as “a pedagogical approach to engaging students in design-build activities that allow them to explore ideas, develop skills and understanding within particular (and often interdisciplinary) disciplines, and build a wide range of learning dispositions and capacities” (p. 6). Educative making can apply to any discipline of study, but it is considered a particularly engaging and effective way to inspire STEM learning (Bevan, 2017; Vossoughi & Bevan, 2014). In this section, past literature related to the Maker Movement is shared, divided into the following subsections: (a) current conceptions of the Maker Movement, (b) theoretical roots of this movement, as identified by other scholars, (c) empirical studies investigating the impact of educative making, and (d) research investigating how to support preservice teachers’ ability to design and facilitate educative making activities in their own practice.

The Maker Movement

The Maker Movement has gained increased attention from scholars, educators and school leaders for the promise it holds to transform STEM education in the twenty-first century (Martin, 2015). Inspired by a popular, grassroots, Do-It-Yourself (DIY) culture, accompanied by increased access to innovative technologies due to dropping prices and open source platforms, the Maker Movement celebrates the transition from technological consumer to producer (Resnick & Rosenbaum, 2013). Represented by "hobbyists, tinkerers, engineers, hackers, and artists committed to creatively designing and building material objects for both playful and useful ends," the Maker Movement has spurred the creation of Maker Faires, makerspaces, and fabrication (or fab) labs in which participants actively create physical objects to share with the world around them (Martin, 2015, p. 30).

It is widely believed that the Maker Movement, and corresponding makerspaces, originated from *hackerspaces*—spaces where computer enthusiasts came together to share ideas, program, and create using a computer (Levy, 2001; Litts, 2015). The transition from hackerspace to makerspace coincided with Dale Dougherty's founding of Maker Media Inc. and publication of *MAKE* magazine in 2005, which provided tutorials and ideas for technology-centered projects (Van Holm, 2014). The following year, the first Maker Faire was held in San Mateo, California, which provided a space for enthusiasts to share their creations. Today, over 130 Maker Faires are held around the world, with the New York and Bay Area events serving as flagship events (http://makerfaire.com); the White House even hosted its first Maker Faire in 2014, with President Obama (2014) calling for "every company, every college, every community, every citizen [to join us] as we lift up makers and builders and doers across the country." Following, key terms associated with the Maker Movement are discussed using relevant literature.

Making. Making has been defined in multiple, yet inconsistent, ways. Honey and Kanter (2013) defined the act of making as "to build or adapt objects by hand, for the simple personal pleasure of figuring out how things work" (p. 4). Others have referred to making as "thinking with your hands," (Sennet, 2009 as cited in Petrich, Wilkison, & Beven, 2013, p. 53) and "playing with real stuff" (Brahms & Werner, 2013, p. 73). Sheridan et al. (2014) connected making to specific disciplines and skills, describing it as "creative production in art, science, and engineering where people of all ages blend digital and physical technologies to explore ideas, learn technical skills, and create new products" (p. 505). In their substantive literature review, Vossoughi and Bevan (2014) acknowledged that existing scholars are inconsistent in how they define making, but concluded, "There does appear to be common agreement that making is a broad category of activity that involves people ideating, designing, and producing physical or virtual objects in the world" (p. 10).

Tinkering. Other terms such as tinkering are also associated with making (Martinez & Stager, 2014). Tinkering is generally considered an iterative and playful approach to problem solving (Resnick & Rosenbaum, 2013), more specifically, the "process of developing a personally meaningful idea, becoming stuck…persisting through the process, and experiencing breakthroughs" (Bevan, Gutwill, Petrich & Regalla, 2015, p. 98). Further, tinkering can be described as a mindset, involving solving problems based on experience, experimentation, and discovery (Martinez & Stager, 2014). Tinkering is generally seen as less formal than making, often as an approach to begin a new project, try new skills, or explore the properties of materials. Research at the San Francisco Exploratorium's Tinkering Studio has documented learning through tinkering in STEM-rich contexts, defined by the use of "scientific and technical tools, processes, and phenomena" which allow open exploration with concepts such as "balance, forces and motion, light, electricity and magnetism, resonance, symmetry and others" (Bevan, et al., 2015, p. 2). Vossoughi, Escudé, Kong, and Hooper (2013) documented tinkering experiences of underrepresented students in an afterschool setting, highlighting the necessity of equity-oriented pedagogical practices.

Design. While making often involves tinkering, it usually involves design. Bennett and Monahan (2013) described design as "the iterative selection and arrangement of elements by which people create artifacts, systems, and tools intended to solve a range of problems" (p. 36). When design is used in an educational context, it is often referred to as design-based teaching or learning and is credited with generating higher intrinsic motivation in students due to the potential for applications to real-world problems (Bennett & Monahan, 2013), something which is often lacking in typical school classrooms (Washor & Mojkowski, 2013). There is also evidence to suggest that learning by design allows students to develop deeper conceptual understandings and self-guided inquiry skills (e.g., Crismond, 2001).

Engineering Design. Distinct from design, engineering design, the process through which engineers solve problems, is another term that is sometimes associated with making (Martin, 2015). Engineering design is also included in the *NGSS* for K-12 students and teachers (NGSS Lead States, 2013). The *Framework*, which guided the drafting of the *NGSS*, describes engineering design as "engagement in a systematic practice of design to achieve solutions to particular human problems" (NRC, 2012, p. 11). See Table 1 for an overview of the engineering design disciplinary core ideas, as described in the *NGSS*.

Table 1.

The Process of Engineering Design, as Described in the NGSS

Define the Problem	Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.
Develop Solutions	Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.
Optimize the Solution	Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.

The distinction between *design* and *engineering design* comes from the systematic nature of engineering. Engineers must clearly define the problem, develop possible solutions, and optimize the solution through systematic tests. In contrast, *design* might not involve such systematic tests; rather, design might be for purely personal projects (e.g., designing a costume.). Martin and Dixon (2016) distinguished between the process of *making* and *engineering design*; while both engineers and makers generally build and adapt technology, *making* encompasses skills and perspectives that are not always associated with engineering (e.g., artistic, playful). While there are many ways for educators to engage students in the process of engineering design in alignment with the *NGSS*, educative making is one motivating and engaging approach (Quinn & Bell, 2013).

Theoretical Roots of the Maker Movement

While there is excitement in current research literature about educative making as a pedagogical approach, the theoretical justification for making to learn exists in past scholarship (Blikstein & Worsley, 2016). Blikstein (2013) presented three "theoretical pillars" of today's Maker Movement: Dewey's (1902, 1938) approach to experiential learning, Papert's (1980, 1991) focus on constructionism, and Freire's (1970) notion of critical pedagogy. However, these scholars were influenced by much earlier conceptions of student-centered learning, advocated for by Rousseau as early as 1762 (Cremin, 1964). Further, Papert drew from Piaget's (1980) ideas when proposing his theory of constructionism (Ackermann, 2001). See Figure 1 for a representation depicting the relationship between these scholars and today's current conception of educative making, as adapted from Blikstein (2013). Each of these areas is discussed in the following subsections using relevant literature to provide additional context and justification for educative making.

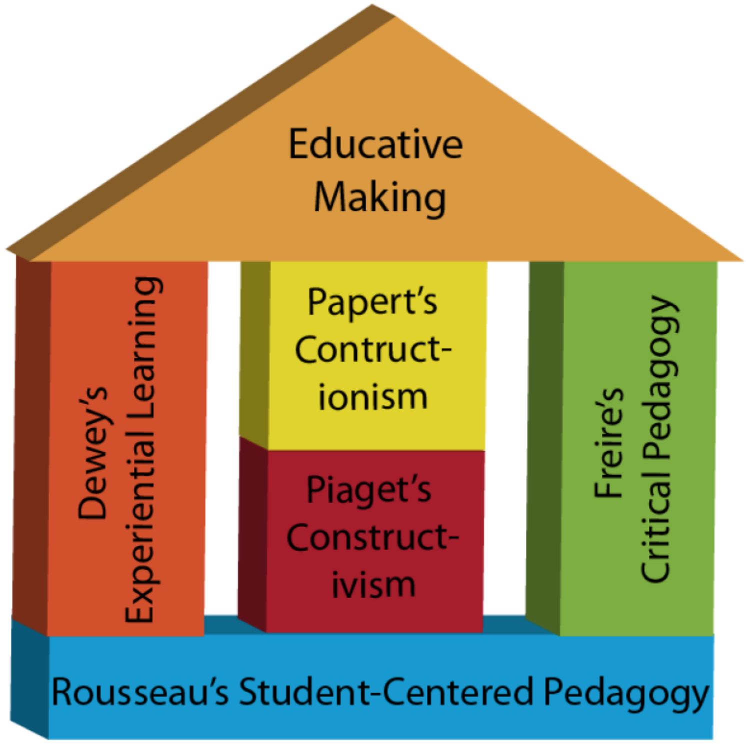


Figure 1. Theoretical pillars of educative making adapted from Blikstein (2013).

Rousseau's student-centered pedagogy. Prescribing a new method of education in contrast to authoritative, transmission models dominant at the time, Jean Jacques Rousseau (1762) advocated for an approach to education that valued the child as a thinking being, with the goal of education to "unfold the powers of children" so they are capable of acting in "accountability to themselves not slavish dependence upon the words of others" (p. 6). He was an advocate of childhood, positing that children should be treated as children, rather than "miniature adults" (Cremin, 1964), and should learn through *experience* (Rousseau, 1762). Rousseau was credited as one of the first to propose student-centered pedagogy (Martinez & Stager, 2013). His work went on to influence eminent scholars of the 19th and 20th centuries.

For example, Friedrich Froebel (1782-1852) drew from Rousseau's student-centered approaches when designing the first kindergarten, or "children's garden", in Germany

(Shonkoff & Meisels, 1990). His model of schooling involved learning through play and from the natural world (Martinez & Stager, 2013). Froebel was also credited with the development and use of "Froebel gifts" to aid in learning, objects such as geometric and pattern blocks, which some claim was the foundation for educational toys and games (Martinez & Stager, 2013).

Similarly, Maria Montessori (1870-1952) was another prominent educational pioneer influenced by the works of Rousseau and Froebel. Both Froebel and Montessori focused on early education, agreeing on the need to engage children in sensory learning experiences. However, while Froebel's kindergarten method relied on "group work and games with an imaginative background and appeal," Montessori's method focused on allowing individuals to develop their own inclinations and interests, namely through interactions with objects (Montessori, 2013, p. v). For example, a typical day in Montessori's school might involve: activities to practice life skills (e.g., cooking, cleaning), manual work (e.g., clay modeling, design), free-play time, and collective gymnastics.

Dewey's experiential learning. As early as 1897, John Dewey (1859-1952) questioned the nature and purpose of education in society. Dewey argued against traditional approaches to schooling which featured adults artificially segregating disciplines of study for children and emphasized memorization of facts, decontextualized from the child's everyday life (Dewey, 1938). Instead, Dewey (1902) advocated for using the child as the "starting point, the center, and the end" of all educational endeavors, similar to Rousseau's child-centered pedagogical approach (p. 13). For Dewey, a child's innate interests and capacities were considered the driving force of educational experiences. Further, Dewey was a proponent of the "continuity of experience," positing that disconnected experiences between home and school might "retard, hamper, or frustrate the spontaneous expression of [the child’s] intellectual life—his thought in action” (as cited in Cremin, 1964, p. 137). Dewey believed that learning occurred through the purposeful progression of carefully selected *experiences*, designed to bring individuals to realize their full worth and potential in the world, or to reach self-realization. To Dewey, education was life, not preparation for future living.

Piaget’s constructivism. Jean Piaget (1896-1980) was a Swiss psychologist who is well remembered for his developmental models of what children can do at specific ages, and his learning theory of constructivism (Siegler, & Alibali, 2005). Rather than viewing children as “empty vessels to be filled with knowledge,” Piaget considered children as “active builders of knowledge – little scientists who are constantly creating and testing their own theories of the world” (as cited in Papert, 1999, p. 1). Piaget (1980) argued that knowledge is *constructed through experience*, and then sorted into pre-existing cognitive schemas; this process is sometimes referred to as building knowledge structures. Individuals can (a) *assimilate* new information, transforming the information so it fits within their pre-existing ways of thinking, or (b) *accommodate* new information, adapting their previous ways of thinking based on new experiences. Piaget also proposed the notion of *equilibration* regarding children’s cognitive development—the process in which children integrate pieces of knowledge into a unified whole as they construct a model of the world that “increasingly resembles reality” (Siegler & Alibali, 2005, p. 31). Piaget’s theory of constructivism was focused on cognitive development and deep understanding; instead of viewing learning as a linear path, it was seen as complex and multi-faceted (Fosnot & Perry, 1996).

Papert’s constructionism. Seymour Papert (1928-2016) is considered the “father” of today’s current Maker Movement (Martinez & Stager, 2013). Having worked with Piaget during the 1960s, Papert was greatly influenced by his work and shared Piaget’s interests in development and epistemology (Ackermann, 2001). Papert later worked at the Massachusetts Institute of Technology (MIT), where he was a pioneer in the field of artificial intelligence and eventually created the first computer programming language for children in 1968, Logo (Martinez & Stager, 2013). In his seminal book, *Mindstorms: Children, Computers, and Powerful Ideas*, Papert (1980) advocated for children to program the computer (as opposed to the computer programming the child). In doing so, Papert (1980) argued that a child "acquires a sense of mastery over…modern and powerful technology and establishes an intimate contact with some of the deepest ideas from science, from mathematics, and from the art of intellectual model-building" (Papert, 1980, p. 5). When programming, the computer becomes a tool to think with and act through: an insight that Papert realized could fundamentally change the way people learn.

Papert and Harel (1991) used Piaget's theory of constructivism to describe their own theory of learning – constructionism:

> *Constructionism—the N word as opposed to the V word—shares constructivism's view of learning as "building knowledge structures." It then adds the idea that this happens especially felicitously in a context where the learner is consciously engaged in constructing a public entity, whether it's a sand castle on the beach or a theory of the universe.* (p. 1)

In short, people learn best when making an artifact for public consumption, something that can be touched, manipulated, or experienced in the world. This shares connotations with Kilpatrick's (1918) conception of the word *project*; "think of a project as a pro-ject, something projected" into the world (p. 4). However, Papert urged scholars to avoid simplifying constructionism to "learning by making," arguing that the theory is "much richer and more multifaceted," with deep implications for education (Papert & Harel, 1991, p. 1).

Freire's critical pedagogy. Paulo Freire (1921-1997) is another significant figure often cited as justification for the Maker Movement (Blikstein, 2013; Blikstein & Worsley, 2016). According to Freire (1970), education either (a) reproduces the status quo, inculcating youth into accepting the world as handed down by older authorities, or (b) becomes the "practice of freedom" – providing an avenue for individuals to critically analyze and creatively act to transform their world (p. 34). Freire (1970) is also remembered for his criticism of the educational "banking system" – the idea that students are "containers" or "receptacles" that require deposits of information from an authoritative teacher. To Freire (1970), these "deposits" created increasingly passive students, unlikely to develop their own critical consciousness; instead, he advocated for students and teachers to act as "critical co-investigators," engaging in dialogue to strive for the "*emergence* of consciousness and *critical intervention* in reality" (p. 81, emphasis in original text). Freire advocated for "problem-posing education," situated in local and personal problems, with the aim of allowing students to critically analyze the realities of their world and begin to conceptualize possibilities for creating change. This pedagogical approach is often called *critical pedagogy* (Blikstein, 2013).

Blikstein (2008) described how Freire's emphasis on humanism is compatible with Papert's focus on creating meaningful artifacts; "constructive, expressive technology makes it possible to further Freire's agenda of emancipation" (p. 7). To Papert and Blikstein, technology was viewed as an agent of emancipation, democratizing the process of invention by placing creative potential in the hands of many, facilitating the transition from consumer to producer.

Emergent Research on Educative Making

While the benefits of educative making exist in past scholarship, current researchers are doing the difficult work of translating theory into practice. Recently, there has been increasing attempts to integrate educative making into informal learning environments, such as museums and science centers (Bennet & Monahan, 2013; Brahms & Werner, 2013; Petrich, Wilkinson, & Bevan, 2013), afterschool clubs (Vossoughi, et al., 2013), summer camps or workshops (Buchholz, Sively, Peppler & Wohlwend, 2014), specialty events (Zosh, Fisher, Golinkoff & Hirsh-Pasek, 2013), and libraries (Bowler, 2014). However, researchers are now shifting attention to how educative making can be implemented in schools to ensure this movement can reach all students (Vossoughi & Bevan, 2014; Wardrip & Brahms, 2016).

Implementing educative making in schools is important because research indicates that today's current students are starting to look outside of formal education to fulfill their curiosities and interests in an increasingly technologically driven world (Dougherty, 2013). Often, school is viewed as separate from students' everyday lives and in opposition to what students want to learn (Barron, 2006). Specific to STEM education, these disciplines are often presented as abstract ideas, decontextualized from students' personal narratives (Eisner, 1985; Bennet & Monahan, 2013). After conducting three case studies of K-12 students who pursued their scientific interests *outside* of formal education, Washor and Mojkowski (2013) provided three reasons that schools cause students to disengage when learning STEM subjects: schools (1) focus too much on assessment, rather than exploration and creativity, (2) rarely provide hands-on, authentic learning opportunities, and (3) only value learning that occurs in school, failing to provide opportunities for students to bring their personal interests into school. Educative making provides unique opportunities to bridge this gap.

When teachers provide opportunities to engage in educative making at school, more students are finding value (Martin & Dixon, 2013). When students are creating with technology, they "become more engaged, spend more time investigating and/or constructing and take ownership for and build confidence in their abilities to learn and understand" (Petrich et al., 2013, p. 56). Moreover, research has positively connected educative making to the development of skills in science and engineering (Bevan et al., 2015), computing (Papert, 1980), math (Garneli et al., 2013), art (Peppler, 2016), writing (Cantrill & Oh, 2016), and spatial reasoning abilities (Leduc-Mills & Eisenberg, 2011). Additionally, research has shown educative making to increase a host of other skills considered crucial for innovation, such as creative confidence (Barron & Martin, 2016), self-efficacy and perseverance in problem solving (Peppler & Hall, 2016), resourcefulness (Sheridan & Konopasky, 2016), and adaptive expertise, or the ability to solve novel problems in new situations (Martin & Dixon, 2016). Finally, educative making was shown as an inviting approach to STEM for students from traditionally under-represented groups, such as girls (Searle, Fields, & Kafai, 2016), and African American or Hispanic students (Vossoughi, Hooper & Escude, 2016), highlighting the value of this approach to broaden the diversity of those pursuing STEM careers.

Specific to science education, Bevan (2017) acknowledged that few existing studies currently demonstrate conceptual science learning gains in students while making, however, work is emerging. For example, Peppler (2013) described how kindergarten students who learned about electronic circuits through an educative making approach developed deeper conceptual gains related to key circuitry concepts such as flow and connectivity when compared to a control group who followed traditional approaches to learning about circuits. Further, Flores (2016) described a variety of educative making activities connected to science concepts, highlighting the necessity of embedding inquiry and invention in the science classroom: Something educative making is extremely poised to accomplish.

Educative Making in Preservice Teacher Education

As this study focuses on the interactions of preservice teachers (enrolled in a Teacher Education Program to receive their elementary Teaching Credential and M.Ed.), research connecting educative making and teacher education is shared in this section. Due to the novelty of educative making as a pedagogical approach, relatively few studies have focused attention on supporting preservice teachers in designing and facilitating educative making activities to support STEM learning.

Some research has focused attention on training in-service teachers to use educative making as a pedagogical approach. For example, Martin et al. (2014) conducted a professional development workshop for middle and high school teachers centered on creating with technology (specifically Arduinos and 3D printers). Results indicated that teachers were proud of their creations but struggled with the use of technology and the programming required. Additionally, Wardrip and Brahms (2014) described their experiences as museum educators working to train local elementary school teachers in educative making, concluding that successful teachers wanted to incorporate making into their classrooms, found creative ways to connect making to other content areas, and did better when there was a designated space for making (as opposed to a mobile cart). Further, Jones, Smith and Cohen (2017) surveyed and interviewed early career teachers, concluding that these teachers saw the value of educative making, frequently making connections to other instructional strategies such as inquiry and project (or problem)-based learning.

However, like was noted in other research (e.g., Martin, et al. 2014), teachers also discussed potential barriers to making in school, such as access to resources and unsupportive administrators.

Fewer studies have focused attention on *preservice* teachers' training and use of educative making. O'Brien's (2016) dissertation investigated preservice elementary teachers' experiences facilitating educative making activities at a School Maker Faire as part of their Science Methods coursework, in fact an earlier iteration of the School Maker Faire studied here. He found four features that influenced the preservice teachers' engagement with children at the School Maker Faire: preparation before the event, types of questions asked, the role of assessment, and the role of parents. Further, O'Brien (2016) highlighted the importance of design thinking in the preservice teachers' planning and facilitation of activities.

Other scholars have created a formalized certificate option situated within a larger Teacher Education Program to expose preservice teachers to educative making. Rodriguez, Harron, and DeGraff (2018) wrote about their experiences organizing a "micro-credential program" called "UTeach Maker" to support preservice teachers in their development of educative making as a pedagogical approach (p. 8). While all preservice teachers enrolled at the university were introduced to making in the first semester of their program, select teachers opted to participate in the UTeach program in the subsequent semester. This program paired preservice teachers with mentors who supported them in completing a maker project that was displayed in a "Maker Showcase." While the micro-credential program is still relatively new (its first instantiation was the 2016-2017 academic year), Rodriguez, et al. (2018) noted their plans to continue the program in future years, partnering their UTeach

Maker graduates (now, practicing classroom teachers) with incoming preservice teachers as a way to build community and ensure educative making takes hold in local schools.

In closing, educative making is still gaining traction in teacher education. The existing empirical studies are so disparate in terms of context and focus that more research is needed to understand best practices for engaging preservice teachers in educative making as a pedagogical approach. This study helps to close that gap.

Chapter III. Conceptual Framework

The conceptual framework for this study is comprised of literature spanning (a) an expansive view of learning as situated in social practice (Lave & Wenger, 1991), and (b) research investigating teaching practices across formal (e.g., Windschitl, Thompson, Braaten & Stroupe, 2012) and informal learning contexts (e.g., Bevan et al., 2017). My conceptual framework was built on the assumption that what teachers do, both the activities they design and the facilitation moves they make, directly impact what children are able to do. The goal for children is to develop positive affinities for the disciplines of science and engineering by engaging in authentic science and engineering practices, as described by the *NGSS* (NGSS Lead States, 2013). To help children accomplish this, teachers engage in specific instructional practices (Ball & Forzani, 2009). In the following sections, I first discuss literature on situated theories of learning. Then, I provide an overview of research investigating activity design and facilitation techniques in informal learning environments (e.g., Bevan et al., 2017), grounded in literature on high-leverage instructional practices (e.g., Windschitl et al., 2012).

Learning as Situated

In a situated theory of learning, learning is conceptualized as more than passively receiving information, more than facts being transmitted from one individual to another. Rather, learning is viewed as engaging in authentic practices, moving from being a legitimate peripheral participant to a fully active member of a community of practice (Brown, Collins, & Duguid, 1989; Greeno, 2006; Putnam & Borko, 2000). Situated learning theory was developed from sociocultural studies of individuals, sharing roots with research traditions in ethnography and anthropology. For example, Lave and Wenger (1991) described the situated nature of learning observed among different groups of individuals, such as midwives in Mexico, tailors in Libya, and butchers in the United States. In each case, learning was not viewed as a simple cognitive process, with knowledge and skills compartmentalized in the head of the learner. Rather, learning was highly dependent on context, situated in social settings and developed through interactions with materials and people over time (Lave & Wenger, 1991; Putnam & Borko, 2000; Sawyer, 2006).

An idea connected to situated learning is that of "communities of practice." According to Wenger (2009) communities of practice are "groups of people who share a concern or a passion for something they do and learn how to do it better as they interact regularly" (p.1). This might include a group of engineers working to solve a problem, a cohort of premedical students learning to diagnose and treat patients, or a group of novice teachers learning to engage children in science and engineering activities. Wenger (2009) defined communities of practice as having three essential characteristics: (1) the domain, (2) the community, and (3) the practice. First, a community of practice must have a *domain*, or identity, that individuals share. Members must outwardly recognize and self-identify as being a member of that community. Second, a community of practice must have a *community* in which they can discuss and engage in joint-activities to improve their learning over time. Finally, a community of practice must have *the practice*. In other words, members must have shared experiences as *practitioners*, a common language and set of resources they can use to make sense of their experiences, together. Wenger (2009) noted that communities of practice take time to develop and must allow for sustained interaction to truly be considered a community of practice. In this work, the cohort of preservice teacher candidates was considered a community of practice (the domain), situated in a larger Teacher Education Program (the community), with the goal of learning how to teach (the practice).

In communities of practice, learning is viewed as increased participation as legitimate peripheral participants (Lave & Wenger, 1991). A novice (or "new comer") to a community of practice should have opportunities to engage in authentic, yet low-risk, peripheral activities. Over time, that individual should be given opportunities to increase their participation by engaging in higher-level tasks. For example, Lave and Wenger (1991) described the process in which young Yucatan Mayan girls learned to become midwives. Because the job of midwives was tied to familial lines, these young girls had opportunities to observe their own mothers act as midwives from a young age. They became accustomated to the midwife way of life (i.e., being on call at all hours of the night) and had opportunities to engage in authentic, yet low-risk tasks (i.e., maternity massages) with guidance. With time and experience, these young women slowly took on additional roles alongside their supervising mothers, before eventually being recognized as midwives themselves. This process shares similarities to apprenticeship models of learning, but, more importantly, is situated in nature and highly dependent upon social relationships and context (Lave & Wenger, 1991).

In this study, both the preservice teacher candidates and children attending the Maker Faire were considered legitimate peripheral participants for different communities of practice. The teacher candidates were legitimate peripheral participants in the community of practice of elementary school teachers. They were enrolled in a Teacher Education Program, actively working with others in their cohort towards earning a Teaching Credential. Further, the Maker Faire was a culminating project in their Science Methods course. The goal of this project was to give teacher candidates opportunities to work with diverse groups of children to facilitate a science or engineering activity, something they will need to do as classroom teachers. The Maker Faire was authentic in that the teacher candidates worked with children at the event, yet low-risk in that teacher candidates were able to work in groups to design and facilitate the activity and received ample feedback from the course instructor before the event. Finally, the event itself might be considered low-stakes in that it was an *informal* event, occurring outside of the traditional school day and free from standardized assessment.

The children who attended the Maker Faire were legitimate peripheral participants in a community of practice separate from the preservice teacher candidates. Lave and Wenger (1991) highlighted that children are “quintessentially legitimate peripheral participants in adult social worlds” (p. 32). They are always working to understand and make sense of the adult world they are so often immersed in throughout their daily lives. In the case of the Maker Faire, the children were legitimate peripheral participants in the communities of practice of *scientists and engineers*. The Maker Faire event was intentionally designed so that children had opportunities to engage in the practices of science and engineering through the support of more experienced individuals (in this case, the preservice teacher candidates).

Finally, situated learning emphasizes engaging in *practices.* Theories on situated learning highlight the necessity of engaging in discipline-specific, authentic practices to move from being a legitimate peripheral participant to being immersed as an active member of a group (Borko, 2004; Lave & Wenger, 1991; Sawyer, 2006). In this study, the teacher candidates and the children both engaged in practices, yet the practices differed for the two groups. The teacher candidates engaged in *teaching practices* to create opportunities for the visiting children to engage in the *practices of scientists and engineers* to make sense of scientific phenomena.

Teaching Practices

Over the past decade, teacher educators have proposed rethinking the act of teaching through identification of *practices* (Ball & Forzani, 2009; Forzani, 2014; Grossman, Hammerness & McDonald, 2009**;** Lampert, 2010; McDonald, Kazemi & Kavanagh, 2013; Windschitl et al., 2012). A focus on practices pays attention to what teachers *do*, more so than what they know and believe (Ball & Forzani, 2009). Some scholars refer to these as "core practices" (e.g., Grossman et al., 2009), while others use the term "high-leverage practices" (e.g., Windschitl et al., 2012). Hatch and Grossman (2009) described high-leverage practices as "approaches to teaching that can be used to address common problems of practice that teachers face and that novices will almost certainly need to employ once they begin teaching," such as leading a group discussion (p. 77). Similarly, Windschitl et al. (2012) defined a high-leverage practice as a "routine activity teachers engage in devoted to planning, enactment, or reflection that are intended to support student learning," noting that things such as taking attendance or passing out materials – activities teachers do on a regular basis – are *not* considered high-leverage because they do not directly enhance student learning (p. 882). Finally, in their substantial literature review of teaching practices, Grossman et al. (2009) concluded that a high-leverage practice should meet the following characteristics:

- Practices that occur with high frequency in teaching
- Practices that novices can enact in classrooms across different curricula or instructional approaches
- Practices that novices can begin to master
- Practices that allow novices to learn more about students and about teaching
- Practices that preserve the integrity and complexity of teaching, and
- Practices that are research-based and have the potential to improve student achievement (p. 277)

Most scholars working to identify high-leverage teaching practices have conducted research in the context of *formal* classrooms (e.g., Ball and Forzani, 2009; Windschitl et al., 2012); however, the context for this study was unique in that it was an *informal* (out-of-school) learning environment designed to help preservice teachers develop practices they would later use in a *formal* (school-based) learning environment. Thus, this study blurs the lines between formal and informal learning environments. In informal environments, learners have more agency in what they do and how they spend their time. They are free to follow their interests. At the Maker Faire, children were free to stay at the stations for as little or much time as they wanted (or however long their parents allowed). Informal learning environments also do not have the affordance of a classroom structure where students return daily to build on ideas and lessons. Likewise, the "lessons" that occurred at the Maker Faire took place over the course of minutes, rather than days or weeks, as is often the case with units of instruction in classrooms. Other scholars have also acknowledged this difference in "grain size," or, in other words, what counts as a "teaching practice" vs. "teaching move" vs. "facilitation technique." As Windschitl et al. (2012) wrote, "Scholars studying [high-leverage practices] in various subject matters differ about 'what counts' as practice and at what grain size novices should begin to approximate teaching activities" (p. 883).

Due to the important components of the Maker Faire that were more aligned with informal learning contexts, I referenced work done by scholars investigating learning in informal, tinkering-style settings (e.g., Bevan et al., 2017; Petrich et al., 2013) to guide my analysis of (a) the activity design, (b) teacher facilitation techniques, and (c) resulting indicators of student learning observed at the Maker Faire. These three areas are discussed in the following sub-sections using relevant literature.

Design of activity. The way in which activities are designed to support learning is consequential (Bevan et al., 2014; NRC, 2000). Researchers at the San Francisco Exploratorium's Tinkering Studio analyzed videos of learners engaged in various tinkering activities to identify productive design principles that supported learners in developing deeper understanding related to science and engineering content, while still honoring their individual pathways. See Table 2 for a summary of their design recommendations (Petrich et al., 2013).

Table 2.

Design Principles for Activities (adapted from Petrich et al., 2013)

Activities and investigations build on learners' prior interests and knowledge.
Materials and phenomena are evocative and invite inquiry.
Tools and concepts of science are a means, not an end.
Multiple pathways are readily available.
Activities and investigations encourage learners to complexify their thinking over time.

In later work, Resnick and Rosenbaum (2013) offered three recommendations for designing activities to support learning in tinkering-style environments. First, tinkering activities should *allow for immediate feedback*. Learners should be able to perform "a series of quick experiments" to get "quick results" (p. 174). Quick experiments and results are important for learners to complexify their thinking. Second, tinkering activities should *generate fluid experimentation*, allowing learners to easily get started and build connections between concepts, materials, and past experiences. Finally, tinkering activities should *support open exploration* using a variety of materials that allow learners to create and iterate projects in alignment with their personal interests (p. 178). Further, they highlighted the importance of designing activities with “low floors” that allow anyone to easily get started, as well as “high ceilings” that allow individuals to complexify their thinking over time (Resnick & Silverman, 2005).

Similarly, Brahms and Werner (2013) provided recommendations for designing activities in the context of makerspaces situated within informal contexts. They partnered with the Children’s Museum of Pittsburgh to design and facilitate learner-centered activities in a museum makerspace. Like recommendations from other scholars, Brahms and Werner (2013) argued for designing activities that allow learners to “play with real stuff” in flexible environments that are accessible to diverse groups of individuals, while also supporting shared experiences between learners (p. 75). Further, they recommended activities should be “simple and intuitive” enough to get started quickly, but also “multilayered” and “robust” to ensure learners can deepen their engagement and conceptual understanding (p. 75).

It is important to note that many of the design recommendations discussed here resonate with student-centered and experiential approaches advocated for by scholars such as Dewey (1938) and Papert (1980) who argued for the importance of engaging children in personally relevant and authentic learning experiences (Blikstein & Worsley, 2016; Resnick & Rosenbaum, 2013). Similarly, designing activities in equitable ways that empower learners with the knowledge and skills necessary to recreate their own futures shares sentiments with Freire’s (1974) notion of critical pedagogy (Blikstein & Worsley, 2016).

Facilitation techniques. Researchers and practitioners from the Tinkering Studio conceptualized facilitation in three distinct moves: (1) spark, (2) sustain, and (3) deepen (Bevan et al., 2015; Gutwill, Hido & Sindorf, 2015). First, a facilitator must *spark* a learners’ interest, possibly through an explicit invitation or through engaging materials and phenomena. Second, a facilitator must *sustain* a learner’s interest. This might take the form of asking questions or offering new materials and tools. Additionally, to sustain a learner's engagement, a facilitator might need to offer encouragement and support works-in-progress (ideas or physical artifacts), "even if they seem counterintuitive or unusual" (Gutwill et al., 2015, p. 162). It is important to provide validation and support to learners. Finally, a facilitator must *deepen* engagement. Deepening engagement might involve challenging a learner to complexify their ideas and designs over time and foster reflection. As Gutwill et al. (2015) wrote: "The purpose of a deepen move is to help learners take their tinkering to new levels, either through greater complexity in their work or more profound thinking about that work" (p. 162). Each facilitation goal—spark, sustain, and deepen—has a series of smaller practices or techniques one might use (see, for example, https://tinkering.exploratorium.edu/sites/default/files/sites/default/files/pdfuploads/facilitation_field_guide.pdf). Table 3 provides an overview of facilitation recommendations from the San Francisco Exploratorium's Tinkering Studio.

Table 3.

Facilitation Moves Adapted from the Tinkering Studio

Facilitation Move	**Practice**
Spark initial interest	Welcome people and invite them into the space.
	Introduce the activity and set the mood for the interaction.
Sustain participation	Value tentative ideas, "mistakes," and wrong directions.
	Support their process in moments of failure and frustration.
Deepen understanding	Guide people to go further than they could on their own.
	Surface connections between projects and links to outside learning experiences.

These facilitation moves, or techniques, share similarities with Windschitl, Thompson, and Braaten's (2018) discourse tools. Windschitl and colleagues (2018) provided a "tool kit" for discourse moves teachers can make to support students' discussion of scientific phenomenon. While these discourse moves were designed for use in formal classrooms, they align with some of the facilitation techniques presented in research on informal, tinkering-style learning environments. Windschitl et al. (2018)'s taxonomy of "talk moves" was organized into seven categories: probing, pressing, follow-ups, opening up cross-talk, wait time, re-voicing, and focusing (p. 63). These talk moves were differentiated by the teacher's purpose in a given context. For example, if a teacher wanted to elicit ideas or activate prior knowledge at the beginning of a unit, she might *probe* students' thinking (i.e., "What experiences have you had with…?"), open *cross talk* between students (i.e., "Does anyone want to respond?"), and use *follow-ups* (i.e., "Can you tell me more?"). If, however, a teacher's goal was to press students for evidence-based explanations about scientific phenomenon at the end of a lesson or unit, she might *press* students (i.e., "Does your explanation fit with the data?") and challenge *follow-ups* (i.e., "How is that different from what was just said?") (Windschitl et al., 2018, p. 63). The goal of all these teaching practices is to positively impact student learning.

Indicators of student learning. Researchers at the Tinkering Studio have documented evidence of learning through close analysis of video featuring learners engaged in tinkering-style activities (Bevan et al., 2017). Through this analysis, Bevan et al. (2017) proposed a set of five learning dimensions (see Table 4). These learning dimensions were selected to represent the dispositions and capacities that learners can develop by engaging in educative making and tinkering activities. Moreover, Bevan et al. (2017) noted that these indicators often overlap and are not mutually exclusive. Additionally, these dispositions and capacities were considered to resonate with other scholars' conceptualization of "twenty-first century skills" (e.g., Trilling & Fadel, 2012). Finally, these indicators move away from viewing learning as the passive transmission of facts; rather, learning is conceptualized through the process of "being, doing, knowing, and becoming." As Petrich et al. (2013) wrote:

> *Our work…is based on an expansive view of learning, conceptualized as a process of being, doing, knowing, and becoming. In this way, we move beyond traditional school-like conceptions (knowing), beyond traditional constructivist conceptions (doing), and include conceptions of the socially situated developing self (being and becoming) as central to activities and processes of learning (p. 53).*

I agree with Petrich et al.'s (2013) conceptualization of learning and sought to find the indicators shown in Table 4 through close analysis of preservice teachers and students interacting in the context of a Maker Faire.

Table 4.

Learning Dimensions from Bevan et al.'s (2017) Framework

Dimension of Learning	**Indicators of Learning**
Initiative and Intentionality	Setting one's own goal Taking risks by working without a blueprint Complexifying projects over time Persisting through and learning from failure Adjusting and redirecting ideas/goals based on feedback
Problem Solving and Critical Thinking	Troubleshooting through iterations Moving from trial-and-error to focused inquiries Developing work-arounds Seeking ideas, assistance, and expertise from others

Dimension of Learning (Continued)	**Indicators of Learning**
Conceptual Understanding	Controlling for variables Constructing explanations Using analogies or metaphors to explain Leveraging physical properties of materials and phenomena to achieve design goals
Creativity and Self-Expression	Responding aesthetically to materials and phenomena Connecting projects to personal interests and experiences Playfully exploring Expressing joy and delight Using materials in novel ways
Social and Emotional Engagement	Building on or-remixing the ideas and projects of others Teaching one another and providing assistance Collaborating and working in teams Recognizing accomplishments and contributions Developing confidence Expressing pride and a sense of ownership

It is important to distinguish the above indicators of learning from the learning outcomes specified in the *NGSS* (NGSS Lead States, 2013). While different, they are not incompatible. Guided by the *Framework*, the *NGSS* represents a significant shift from previous reform documents (i.e., NRC, 1996) in how teachers are asked to engage their students in learning science (NRC, 2012). More specifically, rather than *learning about* the work of scientists and engineers, students should have opportunities to engage in the *practices* of scientists and engineers to make sense of disciplinary core ideas and crosscutting concepts (see Table 5). As described in the *Framework* (NRC, 2012):

> *Engaging in the practices of science helps students understand how scientific knowledge develops…. Engaging in the practices of engineering likewise helps students understand the work of engineers, as well as the links between engineering and science.…The actual doing of science or engineering can also pique students' curiosity, capture their interest, and motivate their continued study. (p. 42)*

By having students engage in authentic disciplinary practices, they gain a deeper understanding of how science and engineering knowledge is constructed and the links between these disciplines. Further, engaging in practices is thought to motivate and enrich learning experiences (NRC, 2012). This view of engaging in practices to learn content and skills aligns well with situated theories of learning by emphasizing the importance of engaging in authentic practices to become a member of a community (Lave & Wenger, 1991). Also, authentic practices of a community extend beyond traditional subject matter (i.e., disciplinary core ideas) to include dimensions of learning such as presented in Table 4.

Table 5.

Science and Engineering Practices, as Described by the NGSS

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Petrich et al. (2013) noted that the dimensions of learning derived from informal, tinkering spaces (presented in Table 4) share a focus on engaging in science and engineering practices like those described in the *NGSS* (shared in Table 5):

> *The Framework [that guides the NGSS] does not define learning solely as the acquisitions of facts or the mastery of skills, but rather includes engagement with the practices of scientists and engineers….This more inclusive definition potentially moves the discourse about learning away from memorization of abstract facts to the development of affinity for and fluency in the ways of knowing, doing, and being (the epistemologies and ontologies) of engineers or scientists (p. 67).*

In other words, engaging in STEM-rich tinkering activities (which provide opportunities for learners to develop initiative, solve problems, express themselves, etc.) also supports learners in developing a deeper understanding of the ways in which scientists and engineers do their work (i.e., ontologies) and come to believe something as true (i.e., epistemologies). This study sought to document evidence of learning occurring in an informal learning environment, linked to activity design and facilitation.

Chapter IV. Research Methodology and Context

The methods of investigation for this study are largely informed by case study research (Yin, 2009). Case studies are considered empirical inquiries, deemed appropriate for use by researchers when the phenomenon of interest, in this case, preservice teacher interactions with children, is embedded in real-life contexts, a School Maker Faire. Further, a case study investigation often deals with situations involving many variables of interest and relies on the triangulation of multiple sources of evidence to assert findings (Yin, 2009). Case study research is best suited for research questions beginning with “why” or “how,” and most often results in descriptive and explanatory findings, rather than generalizable results produced through randomized, controlled experiments more typical in the natural sciences (Yin, 2009).

Study Context

The context for this study was a selective post-baccalaureate Teacher Education Program (TEP) at a large public university in central California. The program is designed for preservice teachers to earn an elementary Multiple Subject Teaching (MST) credential, a secondary Single Subject Teaching (SST) credential, or an Education Specialist Credential (ESC) over the course of the 13-month program. Preservice teachers also have the option to earn a Master of Education in Teaching Degree (M.Ed.) during that time. Each year, roughly 100 students are admitted to the program, distributed among the three credential options: MST, SST, and ESC. Students are organized by cohort and take all classes with their respective classmates working towards the same credential. The program is intense. Preservice teachers work in local practicum (or student-teaching placement) classrooms during the day and attend university courses in the afternoons and evenings. They also complete a year-long research project focused on their own teaching to earn their M.Ed. along with their Teaching Credential.

This study focused attention only on the elementary MST preservice teacher cohort during the 2016-2017 academic year. This cohort had 37 students (herein referred to as “Teacher Candidates” or TCs) enrolled. All 37 TCs consented to participate in the study. See Figures 2-5 for the self-reported demographic information of enrolled TCs, as collected on an initial survey (n=25[2]).

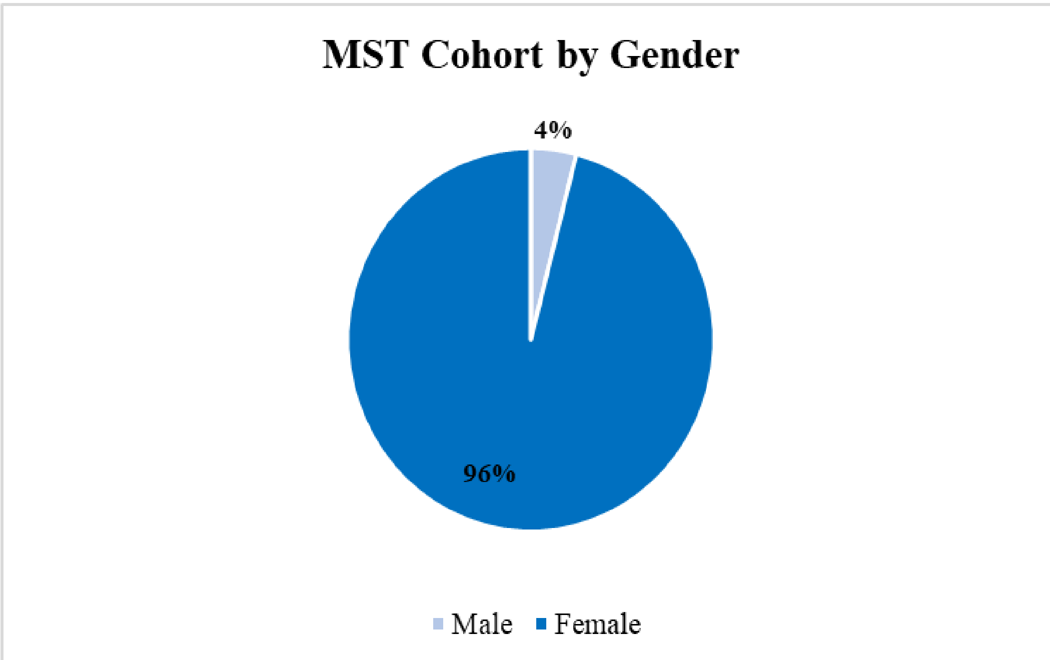


Figure 2. MST cohort by self-identified gender.

[2] While 37 TCs consented to participate in the study, only 25 completed the survey.

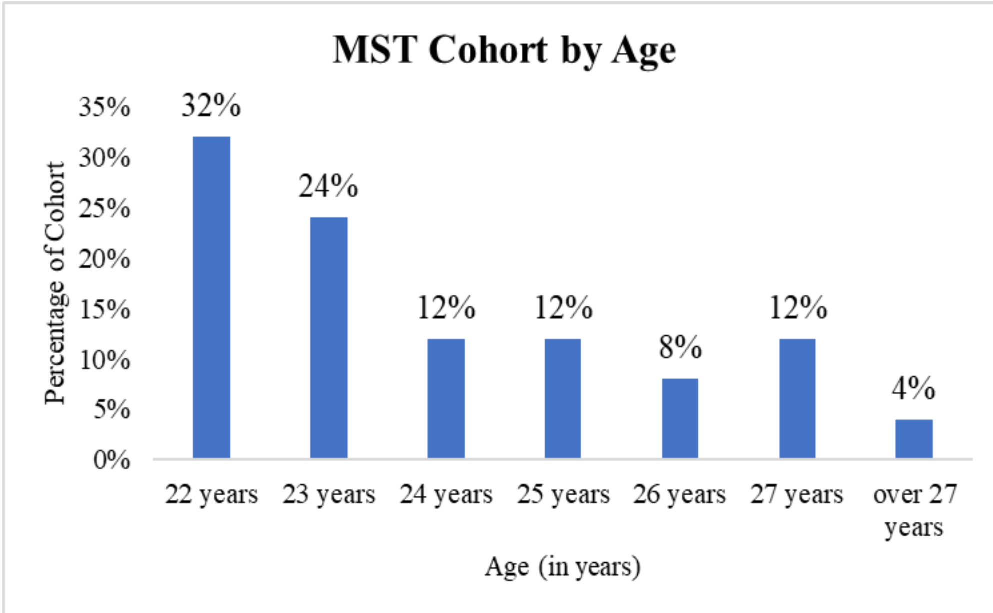


Figure 3. MST cohort by self-identified age.

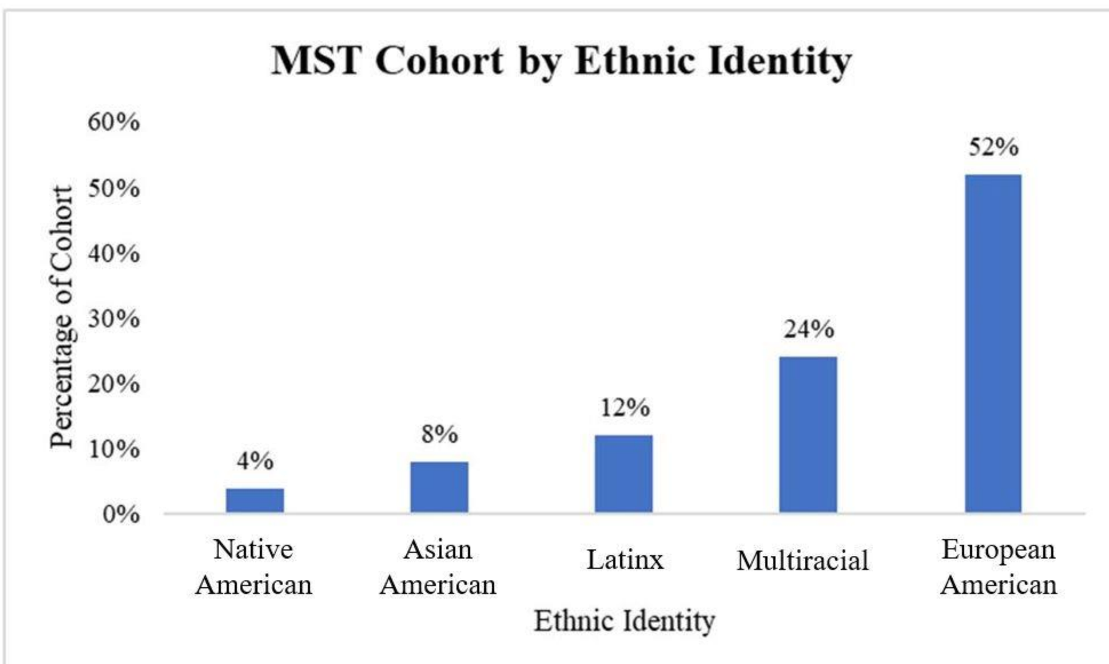


Figure 4. MST cohort by self-identified ethnic background.

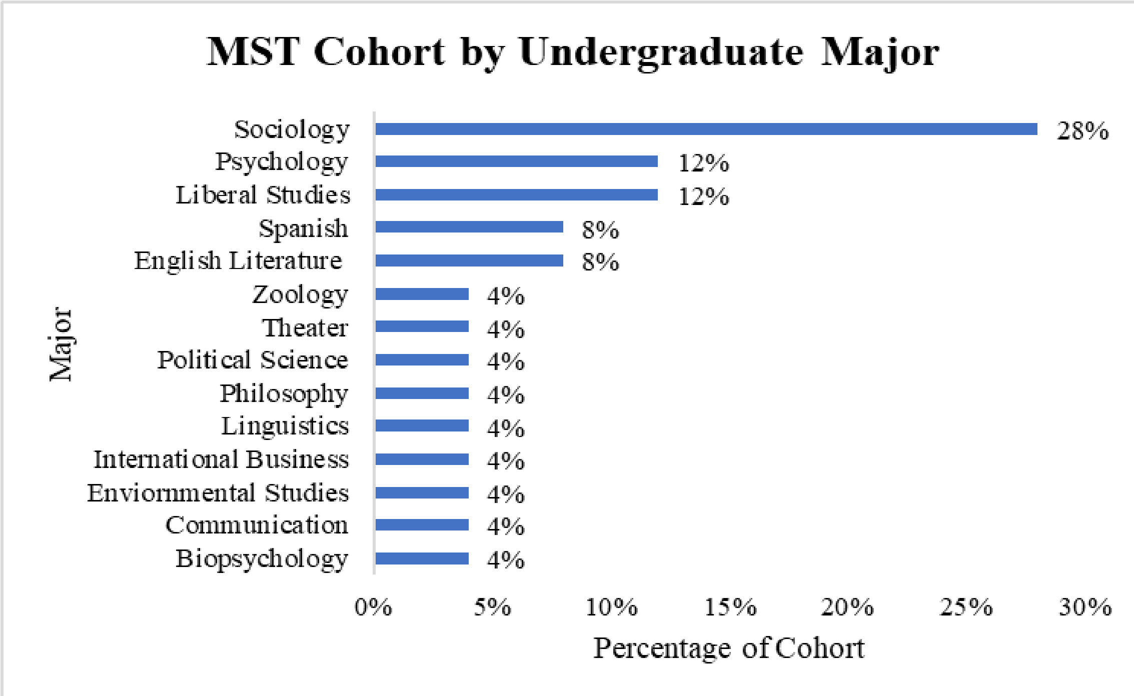


Figure 5. MST cohort by self-identified undergraduate major.

This study focused attention on the TCs during their Science Methods course. The TCs are required to take this course during the second half of their program to learn about research-based approaches for engaging children in learning science and engineering. The course met for 10 sessions (3-hours per session) spanning late-January through June 2017. This class was selected because of its focus on constructionism as a theory of teaching and learning, as well as the inclusion of new teaching standards (e.g., *NGSS*), technologies (e.g., 3D printers), and teaching approaches (e.g., educative making). See Table 6 for an overview of each class session.

Table 6.

Overview of the Science Methods Coursework

Week	Date	Topics Covered
1	January 23, 2017	Introduction to course Overview of *NGSS* Educative making activity: Shadow puppets
2	January 30, 2017	Science vs. Engineering Mystery tube modeling activity Engineering design marshmallow challenge
3	February 7, 2017	Learning progressions: An example through circuits Squishy circuits Valentine's day cards using paper circuits Makey Makey Invention Kit
4	February 13, 2017	Lesson and curricula analysis: *NGSS* Practices Analyze a science lesson for alignment with *NGSS* Analyze an engineering curriculum
5	February 27, 2017	Assessing learning: Developing rubrics and assessments Educative making activity: Foldscopes
6	March 9, 2017	Informal science education: Museum fieldtrip
7	March 13, 2017	Coding and robotics: LegoWeDo and Scratch Prepare for Maker Faire activity
8	April 5, 2017	Mock School Maker Faire
9	April 20, 2017	School Maker Faire
10	May 10, 2017	Reflections and preparation for Teaching Performance Assessments (edTPA)

The culminating assignment for the course was to design an educative making activity aligned to the *NGSS* and to facilitate the activity at a School Maker Faire for local students and their families. TCs worked in small groups of 2-5 to design the learning experience and could select any performance expectation from the *NGSS* to emphasize in their activity. Following, the School Maker Faire event is described in detail to provide additional context.

The School Maker Faire. Throughout the Science Methods course, TCs worked in small groups to design, facilitate, and assess learning aligned to the *NGSS* for guests of the School Maker Faire event (see Harlow & Hansen, 2018; O’Brien, Hansen, & Harlow, 2016). The primary audience for the event included elementary school students in the TCs’ practicum classrooms, as well as their families. Local teachers and administrators were also invited to learn about educative making as a pedagogical approach to engage learners in science and engineering. Over 400 guests attended the event. The types of activities designed by the TCs greatly varied. See Figures 6-8 for example activities at the 2017 School Maker Faire event.

Figure 6. Making pinball machines from recycled materials.

Figure 7. Making and racing apple boats.

Figure 8. Sculpting with conductive and insulating playdough.

Focus Participants

Two TCs were selected as focus participants: Ms. Maggie and Ms. Sarah. These TCs were selected because they consented to participate in additional data collection, including wearing a point-of-view camera at the Maker Faire and participating in individual interviews. Only 3 of the 37 enrolled TCs consented to participating in additional data collection and wore a point-of-view camera while facilitating at the Maker Faire. Further, only 2 of the 3 consenting TCs' video was analyzed (Ms. Sarah and Ms. Maggie). The final TC's footage was not analyzed because the station was designed in a similar manner to the slime station and, thus, analysis seemed redundant. Table 7 provides an overview of the Ms. Maggie and Ms. Sarah's self-reported demographic information.

Table 7.

Self-Reported Demographics of Focus Participants

Name	**Gender**	**Ethnicity**	**Age**	**Undergraduate Major and Minor**
Ms. Sarah	Female	Hispanic	21	Linguistics Major; Education Minor
Ms. Maggie	Female	Multiracial: European/American & Hispanic	26	Philosophy Major; English Minor

Ms. Sarah and Ms. Maggie were in different groups for their design and facilitation of the School Maker Faire activity. Ms. Sarah's group facilitated a slime station in which children made slime to learn about different states of matter. Ms. Sarah worked with three other TCs to design and facilitate the slime station: Ms. Rachel, Ms. Lisa, and Ms. Stephanie. Ms. Maggie's group facilitated a magnetism station where children explored several different magnetic phenomena through open exploration with materials. Ms. Maggie worked with two other TCs to design and facilitate the magnetism station: Ms. Beth and Ms. Peggy.

Data Collection

Sources of data and data collection strategies are described below. Course observations and assignments included data from all the TCs in the Science Methods course, whereas Maker Faire video and interviews were only collected from the focus participants (Ms. Maggie and Ms. Sarah).

Survey. All TCs who were enrolled in the course and consented to participate in the study were asked to complete an initial survey to share background and demographic information with researchers. Twenty-five of the 37 TCs completed the initial survey. The survey included questions related to past teaching experience, comfort with science and engineering content, and student-teaching classroom placements.

Course observations. I attended each session of the Science Methods course as a participant-observer (Spradley, 2016). Participant observation is useful for case study research because it allows researchers to better understand the lived experiences of participants in context (Patton, 2002). When acting as a participant observer, researchers are not passive observers, but may interact with and influence participants' ideas. My role as a participant included working with the course instructor to select and design course assignments and helping to organize the School Maker Faire. I also had served as the primary Teaching Assistant (TA) in the course multiple years prior to the study.

While acting as a participant observer during class, I rotated between groups throughout the class period with a special focus on Ms. Maggie and Ms. Sarah. These focus participants often worked in small groups with other TCs, providing additional points of analysis and opportunities for data collection. Further, I used an ethnographic perspective to inform documentation of field notes (Green, Skukauskaite, & Baker, 2012). By using an ethnographic perspective, researchers can better understand the context and experiences *from the participant's perspective*. Additionally, Delamont (2008) provided guidance on recording field notes. Specifically, each observation began with a concrete overview of the situation, including details such as number of people, seating arrangements, artifacts around the room, etc. Next, I attempted to record as many details as possible during the observation using shorthand annotations. Narrowing the focus of observations to Ms. Sarah and Ms. Maggie helped focus my attention further.

Agar (2000) provided guidance on what to do with field notes once an observation concluded. Specifically, Agar recommended creating analytical memos immediately after observations. I created analytical memos to capture my initial reactions, inferences, and hypotheses or theories for future testing. By recording these in a separate document, I was better able to explicitly track my biases over time. Additionally, analytical memos also helped illuminate "rich points" in the data that were worthy of follow-up later in the study (Agar, 2000). In short, analytical memos tracked my ideas over time in relation to the data collected. Analytical memos were created after each course observation.

Course assignments. In addition to observing each class session, I collected course assignments to help in the triangulation of findings. Assignments included both in-class assignments and homework. If a TC was absent on the day of an in-class assignment, this source of data was not included. See Table 8 for an overview of the course assignments collected for research purposes.

Table 8.

Overview of Course Assignments Collected

Week	Date	Course Assignments
1	January 23, 2017	Drawing of an “Effective Science Lesson” *NGSS* Comfort Level rankings
2	January 30, 2017	Science Life Graphs Science vs. Engineering Exit Ticket
3	February 7, 2017	N/A
4	February 13, 2017	Engineering is Elementary Video Lesson Analysis
5	February 27, 2017	Analysis of Maker Practices
6	March 9, 2017	Fieldtrip Assignment
7	March 13, 2017	Maker Faire Facilitation Guides
8	April 5, 2017	N/A
9	April 20, 2017	N/A
10	May 10, 2017	Drawing of an “Effective Science Lesson” Drafts of Teaching Performance Assessments (edTPA)

Interview data. Interviews were conducted with the focus TCs, Ms. Maggie and Ms. Sarah. Each participant was interviewed before and after the School Maker Faire event. Interview protocols were designed as semi-structured (Brenner, 2006), starting with a series of open-ended questions and follow-up prompts to elicit additional details should a participant need help expanding her ideas about a topic. This type of protocol was selected to allow for flexibility in following up on unanticipated responses from participants. Interviews were conducted on the university’s campus or the TC’s school site, depending on their preference. Length of interview time ranged from 30-45 minutes. See Appendix A for a sample interview protocol.

Maker faire video. Finally, focus participants (Ms. Sarah and Ms. Maggie) were asked to wear point-of-view cameras at the event, specifically TomTom Bandit Action Cameras. Point-of-view cameras have been previously used in educational contexts to generate rich data of student-teacher interactions (e.g., Russ & Luna, 2013). The cameras are small to avoid causing distractions for the TCs or students. The TCs wore the camera on their shoulders, securely attached to a backpack strap. The cameras also provided the affordance of highlighting moments of the video to quickly review after filming. The process of "highlighting" moments is analogous to how one would bookmark a website. Rather than having to review all the camera footage to find a specific moment, the camera software creates bookmark links, allowing researchers to quickly move to the desired timestamp of video. The camera has a special application for use on smart phones, allowing users to view what the camera is currently recording on their connected device, and create highlights of moments for easy review after filming is complete. In this work, the TCs highlighted moments of interesting interaction from their smartphones while facilitating at the event. These moments were further discussed in the follow-up interview.

Ms. Sarah and Ms. Maggie worked in two different groups. Ms. Sarah's group facilitated a slime station in which children made slime to learn about states of matter. Ms. Maggie's group facilitated a magnetism station where children explored several different magnetic phenomena through open exploration with materials. Since the TCs wore the cameras on their shoulders, the video was recorded from their point-of-view. As such, both Ms. Maggie and Ms. Sarah occasionally captured their group members facilitating at the event with children. These instances were transcribed and spliced into episodes for the purposes of analysis. However, due to the nature of the point-of-view cameras, their group members' facilitation was not captured on film *at an equal rate* to that of Ms. Maggie and

Ms. Sarah. Further, since their group members were not focus participants, their individual facilitation techniques were not presented in the findings.

As suggested by Erickson (2006, 2007), the video was considered a "source of data" rather than "data" itself (p. 153). In other words, video records served as a source of data to further define research questions and analytical approaches. Using video as a source of data is rooted in "practices of disciplined observation" (Barron, 2007, p. 160), a cornerstone of scientific inquiry. When applied to the social sciences, disciplined observation typically results in systematic coding of video data in alignment with pre-identified coding schemes.

Derry et al (2010) highlighted two distinct approaches to use in video analysis: inductive and deductive. An *inductive* approach begins with broad research questions, but without a clearly defined analytical approach or guiding theory. After repeatedly reviewing the video collected, researchers can use the "whole-to-part inductive approach" by strategically narrowing their focus and selecting smaller segments of video that highlight themes of interest (Derry et al., 2010, p. 9). In contrast, a *deductive* approach is used to analyze video when researchers have a clear research question with strong guiding theories. In this work, I used a combined approach. I started with an inductive approach, guided by a broad research question (e.g., how do TCs engage learners at School Maker Faire?). After reviewing the collected video, however, I moved towards a deductive approach when the research questions became more clearly defined (e.g., what facilitation strategies do TCs use to engage learners?), and used existing frameworks (Bevan et al., 2014; Bevan et al., 2017) to qualitatively code interactions occurring in the video data.

Data Analysis

I followed a five-tiered process of analysis. In the first tier, video collected at the event was reviewed to create content logs (Goldman & McDermott, 2007; Derry et al., 2010). During this phase, I watched the video, recording actors and actions by timestamp. This provided a large overview of the data collected, spliced into smaller moments of interaction noted for future transcription. See Table 9 for an example content log for the magnetism station.

Table 9.

Example Content Log for Magnetism Station

Moment	Video File	Start Time	End Time	Total Time	Actors	Actions	Notes
1	M00101	0:00:00	0:00:26	0:00:26	Ms. Maggie, Researcher	Testing camera	N/A
2	M00101	0:00:27	0:01:32	0:01:05	Ms. Beth, 2 children	Ring magnet activity	Analyze for dialogue
3	M00101	0:01:33	0:02:16	0:00:43	Ms. Maggie, 1 child from her placement	Ms. Maggie greets student as he passes by station	N/A
4	M00101	0:02:17	0:02:58	0:00:41	Ms. Maggie	Fixing materials	N/A
5	M00101	0:02:59	0:03:30	0:03:31	Ms. Peggy, 4 children	Pendulum activity	Analyze for dialogue

After content logs were created, moments identified as having dialogue around the station's learning objectives (magnetism, states of matter) were organized into *episodes*. An episode was defined as a conversation between a TC and elementary school student (or group of elementary school students) about the station's activities. While the slime station had only one activity (to make slime), the magnetism station had a series of smaller activities (e.g., sorting objects by magnetic properties, making a motor). Due to the nature of the magnetism station, a new episode was created for each “juncture,” or transition, to a new activity (Erickson & Schultz, 1981). Some of the video collected was not considered to be an *episode* because there were no children present, no dialogue, or the dialogue was off-topic from the station’s learning goals. These sections of video were not analyzed. See Table 10 for an overview of the total amount of video data collected, the number of episodes created, and length of time. Note that less overall video was collected at the slime station than magnetism because this station ran out of materials during the event, causing the group to stop facilitating for approximately twenty minutes until materials were restocked.

Table 10.

Overview of Video Data Collected at the School Maker Faire

Station	**Total video collected**	**Total video analyzed**	**% of video analyzed**	**Number of episodes**	**Average length/episode**
Magnetism	78 minutes	59 minutes	76%	24	2 minutes, 46 seconds
Slime	61 minutes	42 minutes	70%	14	2 minutes, 47 seconds

In the second tier of data analysis, episodes with dialogue around the station’s learning objectives were transcribed. Transcription was an iterative and collaborative activity. First, I transcribed talk in the selected episodes, as close to verbatim as possible. Detailed descriptions of actions were also included in the transcript. Next, a group of trained undergraduate researchers reviewed the transcripts for accuracy, clarity, and detail. This frequently resulted in the addition of increased details pertaining to actions (e.g., a TC kneeling to reach the same eye level as a child). As the School Maker Faire was a complex environment, with fluctuating activities and individuals, the process of checking transcripts was essential. Each episode was checked by at least two undergraduate researchers.

In the third tier of data analysis, emergent coding was used to make sense of the interactions occurring between TCs and guests at the School Maker Faire event. During this phase of analysis, differences between the magnetism and slime station emerged as salient. More specifically, as described in the findings, we noted how the interactions occurring at the magnetism station differed substantially from the interactions at the slime station. To help make sense of the varying facilitation strategies and moments of learning observed at each station, I turned to work done by the San Francisco Exploratorium's Tinkering Studio, specifically the Tinkering Learning Dimensions Framework 2.0 (Bevan et al., 2017) and related facilitation techniques (Gutwill et al., 2015). These frameworks served as *a priori* codes to analyze the collected video (Saldaña, 2015). It is important to note that the focus TCs were not given these frameworks ahead of time to inform their design and facilitation.

The group of undergraduate researchers and I iteratively coded the episodes for each station. First, individuals worked independently, coding the written transcript while simultaneously watching the video. Then, the team met to discuss the codes applied. These meetings occurred weekly over the course of the year-long project. When researchers disagreed, we discussed the episode until we reached consensus. Further, we used the Tinkering Studio's video library (https://tinkering.exploratorium.edu/learning-and-facilitation-framework) as a training and calibration tool to confirm that we were viewing events in the same manner as initially proposed in the (2017) framework before starting on the actual data analysis. This online video library is a collection of short clips that feature visitors engaging in tinkering activities and are coded in alignment with the Tinkering Learning Dimensions Framework 2.0 (Bevan et al., 2017). This resource served as a unique opportunity to ensure our coding aligned with Bevan et al.'s (2017) framework. The video library was frequently referenced during team meetings when researchers were unable to agree upon an applied code or were struggling to decide between a few possible codes.

The coding scheme evolved as more episodes were viewed. When the coding scheme was updated, the team reviewed previously coded episodes and re-coded them in alignment with these changes. Erickson (2007) described this analytical process as a "part-to-whole deductive approach;" in other words, researchers looked for specific types of events (e.g., facilitation strategies, indicators of learning) guided by "strong questions, hypotheses, or theories about those events" (as cited in Derry, 2010, p. 18). As described above, the Tinkering Studio's frameworks served as an initial model of what was occurring at the School Maker Faire event, but this model was refined over time based on discussions of the data collected by the team of researchers and reference to the Tinkering Studio's video library. See Tables 11 and 12 for the final coding scheme used to analyze the interactions occurring at the School Maker Faire.

Table 11.

Teacher Facilitation Techniques

Category	Sub-Codes	Magnetism Example	Slime Example
Invitation to Engage	Teacher invites learner to engage with station	"Do you wanna do my magnet station?"	"Are you ready to make slime?"
	Teacher invites learner to engage with materials	"Do you want to try dropping it down [the copper pipe] too?"	"Are you ready for glue?"
	Teacher invites learner to engage in the space	"Come on in here."	N/A
Personal Introductions	Teacher asks learner's name	"And, what's your name?"	N/A
	Teacher shares her name	"Go over there with Ms. Mendiola."	N/A
	Teacher introduces learners to one another	"I want you to drop it down so our friend, Omar, can see."	N/A
	Teacher makes personal connection	"I saw you in the class play!"	N/A

Direct Instruction	Teacher explains content	"The electricity from the battery is coming out through the wire because it's metal."	"It's a solid and a liquid. That's what's kind of cool about slime."
	Teacher explains instructions for activity	"Sort these into two piles: one that sticks and another that does not stick."	"Now, mix this in."
Asks a Question	Teacher asks a question about materials	"What do you notice when you add another [magnet]?	"Would you like any sparkles?"
	Teacher asks a question about process	"How did the magnet fall down – fast or slow?"	"Do you have water and glue in there?"
	Teacher asks a question about content	"What are you noticing about the items that are sticking?"	"Why do you think it's a liquid?"
Re-voicing	Teacher amplifies what learner says for others nearby to hear	"Well, Evan thought it would repel."	N/A
	Teacher re-voices response to learner	Boy: "It stuck." Teacher: "Yeah, that one stuck."	Boy: "It's turning into slime." Teacher: "It is turning into slime."
	Teacher uses learners' own language	"So, you're telling me one of these sides is more *magnety* than the other?"	N/A
Makes a Connection	Teacher makes a connection to other people	"Can you explain it to your mom?"	"Do you agree with her?"
	Teacher makes a connection to other outside experiences	"A car also has a motor in it."	"Is it really like how water feels, like a liquid?"
	Teacher makes a connection to other activities at the Maker Faire	"Remember what happened last time, with the penny?"	N/A
Encourages, Celebrates, and Acknowledges	Teacher shows enthusiasm about what a student is doing or saying	"I like your hypothesis!"	"I like your color!"
	Teacher encourages risk-taking and experimentation	"That's the thing about an experiment. We don't have to know everything."	"What color would you like…Or, you can mix colors."

Encourages, Celebrates, and Acknowledges (continued)	Teacher celebrates moment of joy/excitement	"Whoa! Really strong. It's like invisible. It's cool when things are invisible."	Boy: "Eww!" [giggles] Teacher: "I know! Isn't that crazy?!"
	Teacher acknowledges moment of frustration/confusion	The hardest thing about magnets is you can't see what's going on?"	N/A
Playfully Engages	Teacher does "magic trick"	Teacher: "What about that marble in your hair?" Girl: "Where?" [Teacher pulls marble out from behind her ear.]	"Hold on, we're about to do a magic trick." [Teacher adds liquid starch to turn liquid into slime.]
	Teacher makes silly sounds	"Whoaaaaa…something is happening!"	N/A
	Teacher feigns ignorance	"Did this [metal ring] stick? I can't remember."	N/A
Changes Instruction	Teacher offers a new material	"What about the penny? Does the penny stick?"	"You can mix colors!"
	Teacher offers a new challenge or activity	"I have one more thing with copper if you want to test it out on something different."	N/A
Engages with Observations or Data	Teacher engages with observations or data	"So, it doesn't really seem like the pennies are sticking."	"Keep mixing until it looks like milk."
Crowd Management	Teacher directs crowd to ensure others can participate	"Let's put [these materials] back in [the tray] so it's good for the next person."	"Can you ladies please scoot over a little bit please?"

Table 12.

Student Indicators of Learning

Category	Sub-Codes	Magnetism Example	Slime Example
Initiative & Intentionality	Learner asks a question or sets a new goal for the activity	"What is a motor?"	"Can you put the red food coloring in here?"
	Learner takes control of the materials	"Wait! Let me try."	"I'm ready for liquid starch."
	Learner complexifies ideas/goals based on feedback from materials or people	Teacher: "Try having a pile where they're all stuck together. Then, just do one at a time."	Girl: "Can I do all of the colors?" Teacher: "It'll look brown if you do that.
Problem Solving & Critical Thinking	Learner tries something again and again, multiple iterations	"I did it."	"I'm not going to give up on this."
	Learner moves from trial and error to a more focused inquiry	"I just want to make this really flat."	N/A
Conceptual Understanding	Learner controls for, or attends to, variables	"Now, I'm going to [swing the pendulum] really fast."	"I think I added too much liquid starch."
	Learner constructs verbal explanation	"Copper makes [the magnet] stop and stick instead of just going down. It tries to stick?"	"It's like a solid and a liquid because if you hold it, it's kind of slippery, and when you move it around, it gets solid."
	Learner uses analogies or metaphors to explain	Student describing the motor: "It's like running, running very fast!"	N/A
	Learner expresses an "aha" moment	"It's because of the energy from the battery!"	N/A

Creativity & Self-Expression	Learner playfully explores	Parent: "Do you want to play, or do you want her to show you something?" Boy: "Play."	Girl to her friend: "Slime! Slime! Slime! I'm going to slap at you."
	Learner makes a connection to personal interest, past experiences, or people	"I've played with these [magnet wands] before. We have them in my classroom."	"That's what happened to my friend."
	Learner challenges or disagrees with someone else's idea	"But, copper doesn't stick!"	N/A
	Learner uses materials in novel ways	"Whoa! I didn't even think about [stacking that many magnets]."	"Do you have hot pink?"
	Learner expresses emotion ▪ Joy/excitement ▪ Surprise ▪ Pride ▪ Disappointment/frustration	*Frustration*: "I can't see!"	*Surprise*: "I have to mix it with my hands!?"
Social & Emotional Engagement	Learner collaborates and works in a team	[Matt returns; he helps Eric finish sorting the objects, moving anything magnetic outside the tray.]	Girl 1: "I don't know how to do this." Girl 2: "I think the more you mix it the better it's going to be."
	Learner teaches or helps another individual	[A new group of children approach the station.] Matt: "Watch this!" Eric: "Watch how it goes down [the pipe]."	Boy: "Mom, you're supposed to mix it with your hands."

In the fourth tier of data analysis, codes were entered into NVivo 10. This qualitative software allows researchers to visualize and analyze the coded data in new ways. I used

NVivo to calculate the frequency of each facilitation strategy and indicator of learning by station *and* by teacher to visualize relationships between facilitation techniques and indicators of learning. It is important to note, that due to the high density of video records, I do not claim that the findings are exhaustive. It is possible that indicators of learning were either not caught on film, or not enacted in an elaborated enough manner to warrant an applied code. For example, an indicator of learning such as "learner complexifies ideas/goals based on feedback from materials or people" is difficult to identify in moment-to-moment interactions. Further, the notion of "complexifying" is subjective and contingent upon what a learner knew or understood before engaging in the activity. For indicators such as this, the research team's discussions and consensus were used to justify coding decisions. Instances were only coded if most researchers on the team agreed and were able to justify their coding decisions using substantial evidence from the video.

A mixed-methods approach (Creswell, 2009) was used to make sense of the facilitation strategies and indicators of learning. Qualitatively, a narrative approach was used to highlight moments that epitomized specific facilitation techniques and indicators of learning (Derry et al., 2010). For each category of facilitation coded for, representative cases were pulled from the video. The same process was repeated for the indicators of learning. In other words, I used the NVivo coding to identify instances of salient facilitation techniques and indicators of learning that occurred. Then, I pulled representative cases to describe how the facilitation techniques were enacted, as well as illustrative vignettes to highlight examples for each indicator of learning. In all cases, reference to the video and transcripts were included as evidence for the claims made. Further, this tier of analysis involved triangulating findings across other sources of data (Patton, 2002; Yin, 2009). More specifically, interview data and course assignments were used to supplement what was found in the video data.

Quantitatively, SPSS 11 was used to calculate differences between the magnetism and slime station. A two-tailed *t*-test was used to identify if there were significant learning differences between the stations (Field, 2013). This type of test was selected to compare the difference in means for indicators of learning based on station. The two stations were treated as independent samples because, while there was slight overlap, different children visited each station. To run this test, all indicators of learning (for the slime and magnetism stations, respectively) were summed. Then, a two-tailed *t*-test was conducted to identify if either station had significantly more indicators of learning observed. The null hypothesis was no expected difference between the stations. If, however, there were significant differences observed, then the null hypothesis would be rejected, indicating there were significant differences between the stations. This type of test does not identify the salient differences between the stations though. Instead, qualitative data was used to further tease out potential differences connected to activity design and facilitation.

Chapter V. Ms. Sarah's Slime Station

This finding set focuses attention on Ms. Sarah's slime station. The first two research questions are answered: (1) How did Ms. Sarah design and facilitate the slime station at the Maker Faire? and (2) What indicators of learning were observable among children who visited the slime station at the Maker Faire?

Design of Station

Ms. Sarah's group of four preservice teachers facilitated a slime making activity at the Maker Faire. They articulated that the activity was intended to meet *NGSS* performance expectation: *2-PS-1-1. Plan and conduct an investigation to describe and classify different kinds of materials by their observable properties* (NGSS Lead States, 2013). In her facilitation guide, Ms. Sarah described her desired learning outcomes for this activity:

> *During this experiment we want our students to learn about the changing of physical states….We want them to see that when the ingredients are all added together they form a solution that can be classified as both a liquid and a solid. We also want our students to be able to explain why they would classify each item as a solid, a liquid or both.*

In other words, she hoped they would learn about the science of polymers through making non-Newtonian fluids.

To engage her students in this process, Ms. Sarah used the following materials: glue, water, liquid starch, and "decorations" (e.g., food coloring, glitter). Ms. Sarah described her anticipated design during her pre-interview:

> *We decided that for the purposes of the Maker Faire it would be easier…for management, to just do slime and focus on like the polymers and whether it is a solid*

or a liquid. And, my group can explain that...we are going to have like the little cups already measured out with glue and water and a little section where you get to it…in a factory line. And then you can add the glitter and extra pizzazz.

As described above, Ms. Sarah's design of the slime station was connected to management. She thought the factory line set-up and pre-measured materials would be "easier" to manage during the event. Further, she expressed her discomfort with the science content behind this activity: "My group can explain that." In her pre-interview, Ms. Sarah added she was "excited about the doing, not the explaining, so [she would] be on the other side of the assembly line, where [the children] start making the slime." Indeed, this description matched how Ms. Sarah and her group members facilitated the activity at the Maker Faire. See Figure 9 for an image of Ms. Sarah's station from the event and Figure 10 for a graphical representation.

Figure 9. Ms. Sarah's slime station at the Maker Faire.

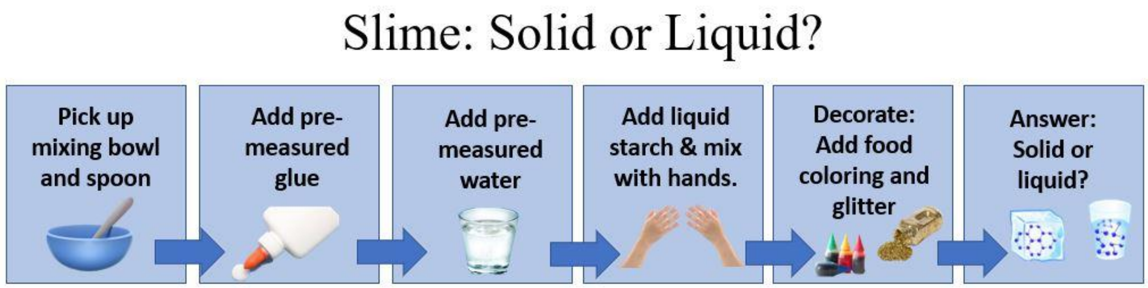


Figure 10. Graphic representation of Ms. Sarah's slime station.

As shown above, Ms. Sarah (and her fellow group members) pre-measured each kind of material in small cups. All students were required to start at one end of the "factory line" where they first picked up a mixing bowl and spoon. This is where Ms. Sarah stationed herself for most of the event (recall, she was excited about the *doing* – or making of slime – not the *explaining* of slime, which was set to occur at the end of the factory line). After selecting a bowl, students were prompted to move down the line as they added glue, water, and, finally, liquid starch to form their slime. After creating their slime, students were given the option to "decorate" by choosing their desired food coloring (i.e., red, green, yellow, blue) and glitter color (i.e., gold or silver). During this final phase, it was common for TCs to prompt students with the following question: "Do you think slime is a solid, liquid, or gas?" To help students answer this question, the TCs displayed the arrangement of molecules in all three states of matter on a poster (like Figure 11). TCs expected students to articulate that slime was neither solid nor liquid, but somewhere in the middle because it did not behave as a typical solid (which retains a fixed volume and shape) or liquid (which assumes the shape of the container it occupies). After being prompted to reflect on the state of matter, students added their slime to a bag to take home.

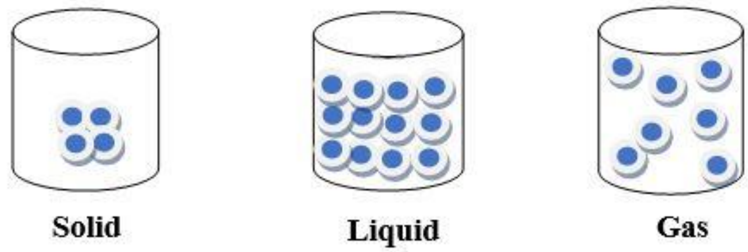


Figure 11. States of matter, as displayed to students at the slime station.

Facilitation Techniques

This section focuses attention on Ms. Sarah's facilitation techniques while at the slime station. She wore the point-of-view camera during the event. I begin this section with an illustrative vignette that depicts common facilitation techniques used at the slime station.

Vignette: Lily's blue, sparkly slime

A young girl in early elementary school named Lily approached the busy slime station followed closely behind by her mother. Ms. Sarah was working at the start of the factory line with another boy and did not immediately notice Lily and her mother approach. When a space finally cleared at the table, Lily and her mother scooted in closer. They looked around, observing others in the space and scanning the materials on the table. Lily sheepishly reached for a bowl and spoon. Lily's mother got Ms. Sarah's attention.

Mom: I think she's ready to start.

Ms. Sarah: Okay, so you need a cup of glue. Here you go.

Ms. Sarah handed Lily a cup of glue, who added the glue to her empty bowl. She carefully used her spoon to scrap out the entire contents of the cup. As Lily added the glue to her bowl, Ms. Sarah took the time to fill additional cups of glue for future visitors. A few moments later, Ms. Sarah noticed that Lily was ready to move on.

Ms. Sarah: Once you have your glue in there, you're going to come to step two and grab a cup of water. You're going to put the water in there too.

Lily proceeded to step two, grabbed a cup of water, and poured it into her bowl. She mixed the bowl's contents as her mother observed, appearing quite focused. In fact, Lily was so focused that she did not immediately notice her mother move down the factory line. When Lily finally looked up from her bowl, she looked around anxiously for her mother. She eventually located her mother and started to walk to her, but hesitated. She made eye contact with Ms. Sarah.

Ms. Sarah: Do you have water in there?

Lily nods her head, "yes."

Ms. Sarah: You can move onto step three, over there.

Lily took this opportunity to rejoin her mother. Another TC in Ms. Sarah's group, Ms. Rachel, took over the facilitation.

Ms. Rachel: And, we have some dye. Red, blue, yellow, or green?

Lily: Blue.

Ms. Rachel: Would you like any sparkles?

Lily nods her head, "yes."

Ms. Rachel: Silver or gold?

Lily: Silver

The above vignette depicts common facilitation techniques used by Ms. Sarah and her group members. Lily and her mother approached a busy station and had to wait for Ms. Sarah to provide the first set of instructions. Ms. Sarah went on to provide additional direct instructions as to which materials Lily should use, and in what order. Lily moved down the line, continuously prompted and guided by explicit directions. The TCs remained in control of the materials throughout the process, asking questions to elicit some student choice (i.e., gold or silver sparkles). At the end, Lily successfully created the TCs' anticipated version of slime.

Figure 12 provides an overview of Ms. Sarah's facilitation techniques throughout the Maker Faire event. As depicted in the vignette, she primarily relied on direct instruction and asking questions. Following, each technique is described through illustrative examples. Facilitation techniques are discussed in order of most common to least common occurrence, whereas unobserved facilitation techniques are not discussed.

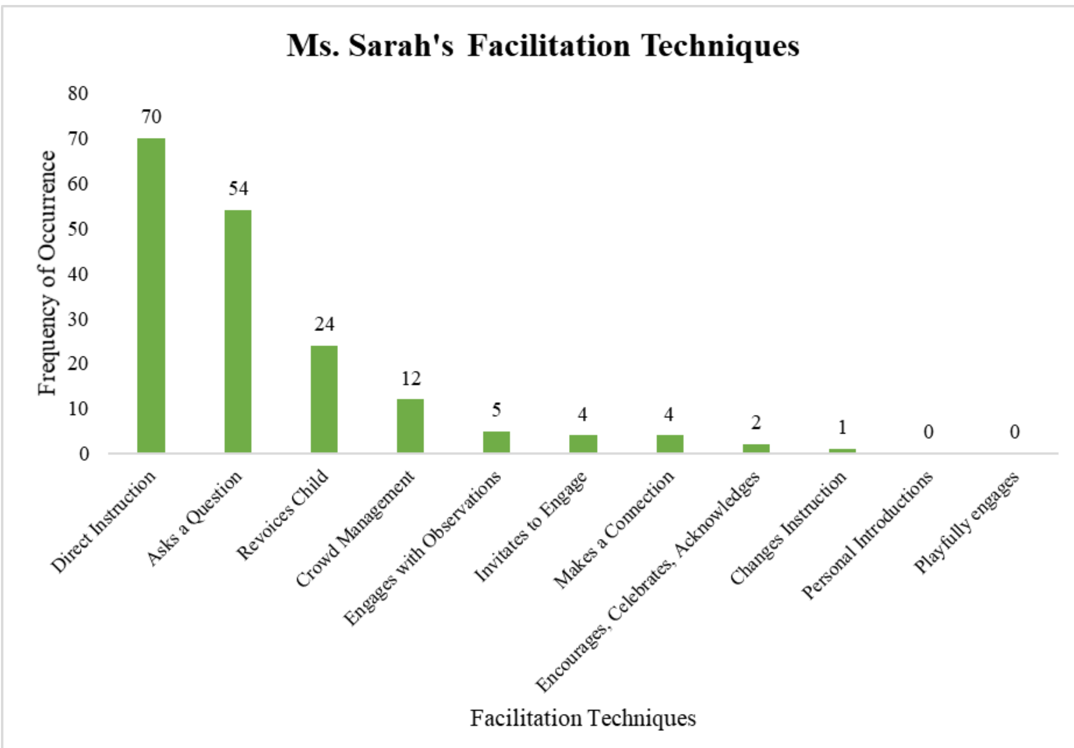


Figure 12. Ms. Sarah's facilitation techniques at the slime station.

Direct instruction. Ms. Sarah relied on direct instruction as her main facilitation technique at the slime station. There were 70 instances of Ms. Sarah telling a child exactly what to do during the event (representing 40% of her overall facilitation techniques). Most often, these direct instructions were connected to materials. For example, Ms. Sarah frequently greeted children who walked up to her station with, "Grab a bowl." After the children picked a bowl, Ms. Sarah often followed up with “grab a cup of glue and put it in [your bowl],” before telling children to “pour all of the water in” and, finally, “add liquid starch and mix it with your hands.” After children added the necessary materials, Ms. Sarah’s direct instructions were more often connected to the *process* of making slime. For instance, Ms. Sarah often instructed children to “start mixing it with [their] hands.” Occasionally, if a child was taking more time than usual to mix her slime, Ms. Sarah would prompt the child, “Keep mixing until it looks like slime.” In each of these instances, Ms. Sarah phrased the instructions as a command or order, rather than an invitation or question.

Asking questions. During the event, Ms. Sarah asked a total of 54 questions (representing 31% of her total facilitation techniques). Ms. Sarah’s questions generally fell into three main categories. See Table 13 for an overview of the types of questions Ms. Sarah asked with counts and percentages.

Table 13.

Types of Questions asked by Ms. Sarah

Type of Question	Examples	Count	Percent
Related to materials	“Would you like red, green, yellow, or blue dye?” “Do you want gold or silver glitter?”	25	46%
Related to process	“Do you have water in there already?” “Do you have your glue and water in there?”	18	33%
Related to content	“What does it feel like?” “Does it feel like a solid or liquid?”	11	20%

As shown in Table 13, Ms. Sarah’s questions fell into three broad categories: (1) related to materials, (2) related to process, and (3) related to content. Nearly half of Ms. Sarah’s questions related to materials. Most often, these questions were connected to the “decorating” portion of the station: choosing the color of food coloring and glitter to add.

Additionally, Ms. Sarah asked 18 questions (33%) related to the process. In these cases, Ms. Sarah was seemingly checking to see where children were in the process of making slime so that she could help them with the next step. For instance, if a child had glue and water in his cup, he was ready to add liquid starch. Finally, Ms. Sarah asked the fewest questions about content. Only 11 of her questions (or 20%) related explicitly to the desired learning outcomes of the station (differentiating between a solid and a liquid).

Re-voicing. During the event, Ms. Sarah frequently repeated, or re-voiced, what a child said back to the same child. Ms. Sarah re-voiced a child's response 24 times over the course of the event (comprising roughly 20% of her facilitation techniques). The following excerpt from a transcript represents a common occurrence in Ms. Sarah's facilitation at the slime station:

Ms. Sarah: What color glitter would you like – gold or silver?

Child: Gold.

Ms. Sarah: Gold? Okay, here you go (*pours gold glitter into child's bowl*).

It is important to note that in all instances of Ms. Sarah re-voicing a child's response, it was never to facilitate a group discussion with multiple students, as is often the purpose of teachers' re-voicing. Rather, Ms. Sarah simply repeated a child's response back to the *same* child, as if checking or confirming that she correctly heard and understood the initial response.

Crowd management. There were 12 instances of Ms. Sarah engaging in crowd management, characterized by her prompting the crowd to move down the table to make room for new arrivals. In each instance, Ms. Sarah was addressing multiple people and often included hand motions to signal that people should move down. For example, immediately preceding the still image shown in Figure 13, Ms. Sarah asked, "Can you girls scoot down to the end?” while gesturing in that direction (arrow included to emphasize motion). This was an example of Ms. Sarah engaging in crowd management at the event.

Figure 13. Ms. Sarah engaging in crowd management.

Engaging with observations or data. During the event, Ms. Sarah made 5 explicit connections to observations or data. Considering the nature of the slime station and the anticipated learning outcomes, Ms. Sarah’s observations were always connected to the material properties of slime. For example, when Ms. Sarah was working with a young boy and his sister, she said, “Definitely stir a little more so that it is nice and soft.” The description of “nice and soft” qualified as an observation at the slime station. Further, another instance of Ms. Sarah engaging with observations occurred when working with a young child (see Figure 14). This child added water and glue to her bowl. Then, Ms. Sarah prompted her to “keep mixing until it looks like milk.” In this case, Ms. Sarah informed the child that the contents of her bowl should look “like milk” before moving onto the next step. The descriptor “like milk” qualified as engaging with observations or data. Note that “like milk” was also considered a connection to outside experiences, so this interaction was coded for both engaging with observations or data *and* making connections (discussed below).

Figure 14. Child mixing slime “until it looks like milk.”

Invitations. Over the course of the event, Ms. Sarah only explicitly invited 4 children to engage with her station. Each time Ms. Sarah personally invited a child, adult, or group to engage, she asked some variation of, “Would you like to make some slime?” Ms. Sarah only offered invitations when the station was relatively unoccupied. During most of the event, however, the slime station had a line of people waiting, possibly making explicit invitations seem unnecessary, or even counter-productive since it would contribute to the time people had to wait to make slime. See Figures 15 and 16.

Figure 15. Slime station during peak attendance.

Figure 16. Slime station while relatively unpopulated.

Figure 15 shows a typical scene at the slime station. There were multiple children actively making slime. Further, a line was beginning to form to the left of the station. In contrast, Figure 16 shows a scene immediately preceding an explicit invitation from Ms. Sarah. A child and adult approached the station, which had plenty of open space at the time, and were greeted by Ms. Sarah who asked, “Are you ready to make slime?” Ms. Sarah only offered explicit invitations when there was the space and time to do so. Invitations represented 4% of Ms. Sarah’s overall facilitation techniques captured on film during the event.

Making connections. During the event, Ms. Sarah made 3 explicit connections to outside experiences when facilitating with children. For example, when a child was mixing his slime, Ms. Sarah said, “You’re going to mix really good until it looks like milk.” In this case, Ms. Sarah made a connection to milk: something the child has most likely experienced in his life. Ms. Sarah made other connections to outside experiences when discussing what slime (or other non-Newtonian fluids) might be used for in everyday life. Ms. Sarah shared that this type of material is used to “cover pot holes” and “on the bottom of shoes.” In each of these instances, Ms. Sarah made a connection to an outside experience to further the children's thinking about slime.

Additionally, Ms. Sarah made 1 explicit connection *between* children at her station. Ms. Sarah asked a younger child, Olivia, what state of matter she thought slime represented. After she seemed sure her answer of "liquid" was correct, Ms. Sarah made a connection to two older girls, Katie and Jessica, who were also present at the station, bringing them into the conversation (see Figure 17). The following transcript depicts the interaction.

Ms. Sarah: What does it feel like? Does it feel like a solid, a liquid, or a gas?

Olivia: A liquid?

Ms. Sarah: A liquid. Why a liquid?

Olivia: Because it has water in it.

Ms. Sarah: What do you ladies think? Is it a solid, liquid, or a gas?

Katie: Neither.

Ms. Sarah: Neither. Why?

Katie: Because it's like…I don't know. I can't explain it.

Jessica: I think it's between a solid and a liquid.

Ms. Sarah: Between a solid and a liquid. Why?

Jessica: Because if you hold it, it's kind of slippery, and when you move it around, it gets solid.

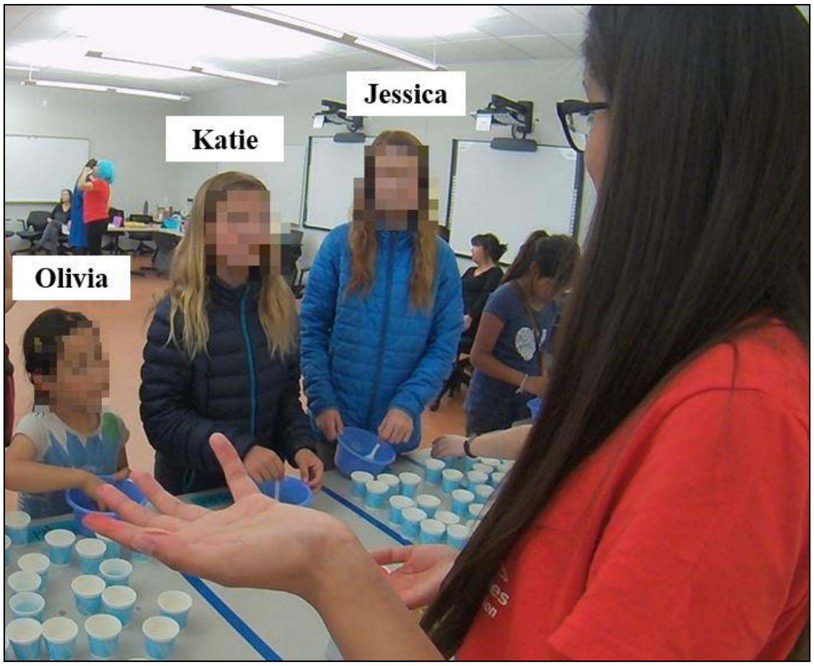


Figure 17. Ms. Sarah making a connection between children.

Encouraging, celebrating, and acknowledging. During the event, Ms. Sarah *encouraged* risk-taking and experimentation only once. This interaction occurred with Olivia, shown in Figure 17 above. When Ms. Sarah asked what color of dye she wanted to add to her slime, Olivia hesitated, seeming discontent with the options presented. This caused Ms. Sarah to add on to her initial question after a three second pause, “Or, you can mix colors!” This encouragement seemed to be exactly what Olivia needed. She immediately responded, “Red and blue. Red and blue make purple.” This quick response after an unusually long pause to Ms. Sarah’s first question indicated that she potentially had pre-selected purple as her desired color of slime. When Ms. Sarah’s facilitation changed, to open the possibility of *more than one color*, Olivia seized the opportunity. She made her purple slime. Up until this point during the event, Ms. Sarah had not offered to add more than one color of dye to a child’s bowl. This interaction was also the only time Ms. Sarah changed her facilitation based on a child’s response, in this case, a non-verbal response.

Additionally, Ms. Sarah expressly *celebrated* one moment with a young child, Mia, and her mother. As mentioned earlier, the slime station ran out of materials (specifically, liquid starch) for roughly twenty minutes during the event. During this time, people still approached the station hoping to make slime. This prompted one of Ms. Sarah's group members to improvise. Rather than using liquid starch to create slime, she borrowed borax from a station nearby and used a different recipe to make a modified version. When Mia and her mother approached Ms. Sarah, the following exchange occurred:

Mia: It's working great!

Ms. Sarah: Is it working for you?

Mia: Yeah!

Ms. Sarah: Oh, my goodness.

Mom: It's kind of coming together...we're the borax experiment.

Ms. Sarah: And, it actually worked! Yay!

The above transcript depicts a time when Ms. Sarah verbally celebrated with a child. Interestingly, this celebration only occurred due to an unforeseen problem: running out of materials. This problem caused Ms. Sarah's group member to improvise, which ultimately led to the celebration. However, if the group did not run out of materials, this celebration would not have occurred in the same manner.

Changing instruction. As mentioned earlier, Ms. Sarah explicitly changed her instruction based on a students' idea only once during the event. Recall when Ms. Sarah encouraged risk-taking by combining more than one color of food dye for Olivia, shown in Figure 17. This instance also marked the first and only time that Ms. Sarah changed her instruction during the event. Up until this point, she had only offered one color of food dye per child. After this interaction, however, Ms. Sarah often offered more than one color of food dye to children; usually phrased as, “Which color would you like? Or, you can mix colors.”

Indicators of Learning

In this section, I describe indicators of learning for the slime station. It is important to note that all episodes from the Maker Faire video were included in the analysis for this section (not just the episodes where Ms. Sarah was facilitating individually). Due to the placement of the cameras, Ms. Sarah occasionally captured her group members on film facilitating at the event or co-facilitated an activity with her group members. Thus, all children who visited the slime station and were captured on video are included in this analysis.

Over the course of the event, a total of 46 children engaged in the process of making slime. On average, children stayed for 6 minutes and 10 seconds. The shortest time a child stayed at the slime station was just over 2 minutes. The longest time a child stayed at the slime station was 12 minutes and 42 seconds. Figure 18 shows the frequency of occurrence of the five indicators of learning described in Chapter 3, across the 46 children who visited the slime station.

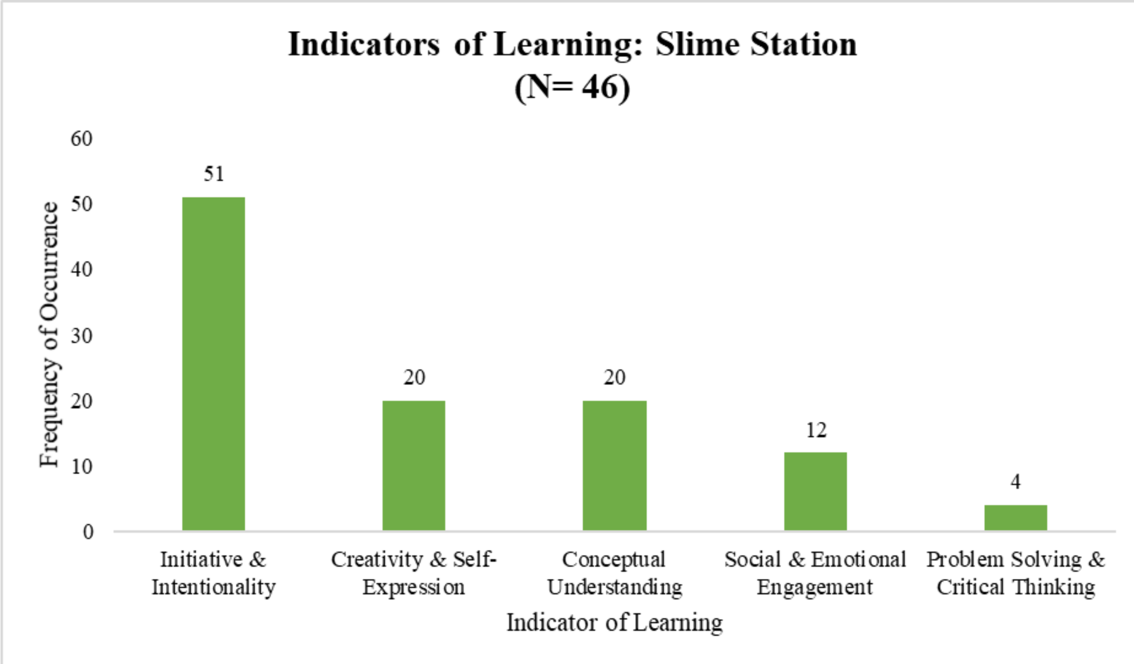


Figure 18. Indicators of learning observed among children at the slime station.

Of the indicators of learning coded for, children visiting the slime station demonstrated *initiative and intentionality* more than twice as many times as any other indicator of learning. The next most frequent indicators of learning were *conceptual understanding* and *creativity and self-expression*, with slightly fewer instances of *social and emotional engagement.* The children at the slime station only demonstrated *problem solving and critical thinking* four times over the duration of the event. Each of these are described in more detail below (from highest frequency of occurrence to lowest) using illustrative examples.

Initiative and intentionality. At the Maker Faire, there were 51 instances of children demonstrating *initiative and intentionality* while visiting the slime station. Table 14 shows the sub-codes under initiative and intentionality, with total counts for each code.

Table 14.

Indicators for Initiative and Intentionality at the Slime Station

Indicator of Initiative & Intentionality	Frequency of Occurrence
Asks a question	45
Takes control of the materials	6
Complexifies ideas/goals based on feedback	0
Persists through and learns from failure	0
Sum	51

Asking questions. As shown in Table 14, the highest frequency of children expressing initiative and intentionality at the slime station was through asking questions. Most of these cases involved children asking the TCs questions to ensure they were following the correct steps to make slime. For instance, one boy, Billy, demonstrated initiative by asking 4 questions over the 6-minute time span he spent making slime (see Table 15). In all 4 cases, his questions were aimed at the TC with the goal of better understanding the task at hand. In 3 of the 4 cases, Billy asked Ms. Sarah if he should pour the entire contents of the small cups (i.e., glue, water, liquid starch) into his bowl. In the final case, he asked Ms. Sarah if he could keep the slime at the end. All these cases demonstrate initiative on Billy’s part – he was making sure he understood how to make slime correctly – but, his initiative was connected to procedural understanding rather than conceptual understanding. It seemed as if Billy thought the main objective of the station was to make slime, not to learn about solids and liquids.

Table 15.

Billy Taking Initiative by Asking Questions at the Slime Station

	Speaker	Utterance	Activity	Image
1	Billy: Ms. Sarah:	And, do I just pour the whole thing in it? Yes, pour it in there.	*Billy waits to pour the glue into his bowl until receiving confirmation from Ms. Sarah.*	
2	Billy: Ms. Sarah:	Do we get to keep the slime? You do get to keep the slime.	*Billy adds glue to his bowl and begins to mix contents using spoon.*	
3	Billy: Ms. Sarah:	Do we pour all of the water? Pour all of the water. And, you have to mix it.	*Billy moves onto the next step. Ms. Sarah hands him a cup of water. He hesitates before adding the water to his bowl.*	
4	Billy: Ms. Sarah:	Add all of it? Yes, get it all in there and mix it with your hands.	*Ms. Sarah adds yellow food dye to Billy's bowl. She hands him a cup of liquid starch. Again, he hesitates before adding the new material.*	

Another boy, Jack, also demonstrated initiative by asking questions of the TCs at the slime station. Unlike Billy, however, Jack continuously asked the *same* question. More specifically, he asked some variation of, “Can I touch it?” Jack had already added glue, water, liquid starch, and decorations to his bowl and was ready to begin mixing the slime with his hands when he asked this question initially. However, the station had become busier than usual and Jack’s question was not heard by any of the TCs facilitating at the slime station. This prompted Jack to repeat his question 5 more times. Finally, one of Ms. Sarah’s group members heard and acknowledged Jack’s question, giving him permission to touch the slime with his hands.

Figure 19. Jack asking, “Can I touch it?” again.

Taking control of materials. Besides asking TCs questions to confirm they were following the correct procedures for making slime, others took initiative by *requesting materials*. This occurred 6 times at the slime station. For example, one teenage girl, Jasmine, requested materials several times from Ms. Sarah. In some cases, these material requests were for herself. Other times, her material requests were made for friends who were also making slime, as seen in Figure 20. Jasmine noticed that her friend needed liquid starch. This realization prompted her to lean in, make eye contact with Ms. Sarah, point to the liquid starch, smile, and ask, “Can we take one?” Ms. Sarah promptly responded, “Yes, go ahead.” This instance of initiative allowed Jasmine (and her friend) to continue making slime.

Figure 20. An example of Jasmine taking initiative by asking for materials.

Creativity and self-expression. There were 20 instances of children demonstrating creativity and self-expression captured on film at the slime station. See Table 16 for an overview of these indicators.

Table 16.

Indicators for Creativity and Self-Expression at the Slime Station

Indicator of Creativity & Self-Expression	Frequency of Occurrence
Expresses emotion	8
Playfully explores	5
Makes a connection	4
Uses materials in novel ways	3
Challenges or disagrees with someone’s idea	0
Sum	20

Expresses emotion. The indicator of creativity and self-expression most frequently observed among children visiting the slime station was expressing emotion. There were 8 instances coded for emotional expressions. The most often emotion expressed was surprise. Students seemed surprised when TCs prompted them to mix the slime with their hands, as indicated by raises in tone of voice and eyebrows. Besides surprise, some students expressed joy or excitement about the slime. Finally, one student expressed pride over her creation. Recall Mia and her mother, or the "borax experiment" group, that Ms. Sarah celebrated. Ms. Sarah's celebration came after Mia announced her slime "was turning out great!" This was the only moment of outward pride observed at the slime station.

Playfully exploring. Five students exhibited the indicator of playfully exploring. All these students were observed staying at the slime station longer than the group's average (of 6 minutes and 10 seconds). Further, these students displayed obvious signs of enjoyment, such as laughing, giggling, squealing, and play-fighting with their slime. For instance, consider the following exchange between two young girls, Amy and Anna, shown in Table 17. These girls playfully explored their slime, seemingly expressing emotion, specifically joy or excitement, as they played.

Table 17.

Amy and Anna Playfully Exploring Slime

	Speaker	Utterance	Activity	Image
1	Amy:	♫ I'm making slime. I'm making slime. ♫	*Amy is mixing her slime. She begins to sing as she continues mixing with her hands.*	
2	Amy:	I'm going to hit with you my slime!	*Amy playfully teases Anna, pretending she is going to hit her with the slime. Both girls laugh, seemingly enjoying the activity.*	

Makes a connection. Another indicator of creativity and self-expression was making connections, observed 4 times throughout the event. These connections included reference to past experiences, people, and contexts outside of the Maker Faire. For example, when one girl asked Ms. Sarah to add all the food coloring options to her slime, another boy nearby stated: "If you do that, it will look brown…that's what happened to my friend." This comment showcased a connection this boy made between a past experience (his friend making brown slime) and the current activity. This was also coded as an example of social and emotional engagement (discussed more below) because it was an offer of help to another individual.

Uses materials in novel ways. Finally, there were 3 instances of children using (or suggesting that they would use) materials in novel ways while at the slime station. Something was considered “novel” if someone had not previously used the materials in the same way as those who visited the station before. Two of these instances were connected to food coloring. First, as noted earlier, one girl wanted to add all the food dye colors to her slime. Despite not doing so (for fear of the slime turning brown), this marked a novel use of the materials presented that had not been previously used by others at the station. Second, another girl attempted to make hot pink slime by combining different amounts of yellow and red. The final example of students using materials in a novel way occurred when one girl, Jessica, asked to pour her slime on the table (see Figure 21). In this case, she articulated that a liquid often takes the shape of its container, so she wanted to see what would happen if she emptied her slime onto the table.

Figure 21. Jessica (left) asking to take her slime out on the table.

Conceptual understanding. There were 20 instances of children demonstrating conceptual understanding at the slime station. Table 18 shows the sub-codes under conceptual understanding, with total counts for each code. Each area is discussed through relevant examples from the video.

Table 18.

Indicators for Conceptual Understanding at the Slime Station

Indicator of Conceptual Understanding	Frequency of Occurrence
Constructs verbal explanation	17
Controls for or attends to variables	3
Uses analogies or metaphors to explain	0
Expresses an "aha" moment	0
Sum	20

Constructing verbal explanations. Most conceptual understanding that was evident from the video analysis was in the form of verbal explanations constructed by the children. Often, these verbal explanations came after a teacher prompted the child with the following question: "Do you think slime is a solid, liquid, or a gas?" Recall Jessica's response to this question (shown in Figure 17): "I think it's between a solid and a liquid…because if you hold it, it's kind of slippery, and when you move it around, it gets solid." This was an example of conceptual understanding related to the learning goals of distinguishing between solids and liquids.

Yet, not all verbal explanations of content were correct. For instance, consider the following exchange that occurred between Ms. Sarah and a boy, Matthew, after he added glue and water to his mixing bowl.

Ms. Sarah: So, what do you think it is?

Matthew: A liquid.

Ms. Sarah: A liquid. Okay. Once I pour this [liquid starch] in, you're going to mix it with your hands.

(*Ms. Sarah helps Matthew add liquid starch. He begins to mix with his hands. She re-approaches a few seconds later*).

Ms. Sarah: Do you think it's a solid, liquid, or a gas?

Matthew: A liquid.

Ms. Sarah: Why do you think it's a liquid?

Matthew: Because it's still kind of gooey.

Ms. Sarah: It's still kind of gooey.

Matthew: It's not like completely solid.

Ms. Sarah: It's not like completely solid. So, the more you mix it, the more firm it gets.

In the exchange above, Matthew's justification of his response "liquid," was coded as constructing a verbal explanation. Even if Matthew's claim was incorrect, it still provided valuable information to the TC about what he was thinking in the moment. TCs considered an answer "correct" if a child stated that slime was somewhere between a solid and a liquid.

Controls for, or attends to, variables. Finally, the only other indicator of conceptual understanding observed among students at the slime station was "controls for, or attends, to variables." This was only observed 3 times throughout the event. In all three instances, students were attending to the amount of materials they added as a variable. For example, Katie, shown in Figure 22, remained convinced that she added too much liquid starch. This was evident by her stating, "I think I added too much liquid starch?" *twice,* as if seeking feedback from Ms. Sarah. Both times, the tone of voice rose, indicating the questioning nature of her statement.

Figure 22. Katie (left) attending to variables, specifically the amount of liquid starch.

Social and emotional engagement. There were 12 instances of children demonstrating social and emotional engagement at the slime station. Table 19 shows the sub-codes under social and emotional engagement, with total counts for each code. Following, each area is discussed using illustrative examples.

Table 19.

Indicators for Social & Emotional Engagement at the Slime Station

Indicator of Social & Emotional Engagement	Frequency of Occurrence
Collaborates and works in a team	8
Teaches another individual	4
Sum	12

Collaborates and works in a team. There were 8 instances of children *working in a team* at the slime station. This was most often connected to the decorating portion of the activity. For example, one girl, Ava, was ready to select her food dye color, but the TCs were busy working with other children. This prompted Ava's friend, Violet, to get a TC's attention by asking, "Is she ready for her decorations?" Immediately after, the TC helped Ava select food coloring and glitter.

Figure 23. Violet helping her friend, Ava, by getting the TCs attention.

Teaches another individual. There were 4 instances of children *teaching others* at the slime station. Three of these instances involved children teaching another child, whereas one instance involved a child teaching an adult. For an example of the latter category, recall Billy. Billy was visiting the slime station with his mother and younger sister and frequently demonstrated initiative by asking questions throughout the process to ensure he was following the correct steps (see Table 15). Billy's mother helped his toddler sister make her slime as Billy made his own. After Ms. Sarah instructed Billy to mix the slime with his hands, he noticed his mother was still mixing his sister's slime with a spoon. This realization prompted Billy to say, "Mom, you're supposed to mix it with your hands" (see Figure 24).

Figure 24. Billy instructing his mother to mix the slime with her hands.

Problem solving and critical thinking. Only 4 instances of problem solving and critical thinking were observed at the slime station. See Table 20.

Table 20.

Indicators for Problem Solving & Critical Thinking at the Slime Station

Indicator of Problem Solving & Critical Thinking	Frequency of Occurrence
Tries something again and again, multiple iterations to troubleshoot	4
Moves from trial and error to focused inquiry	0
Sum	4

Tries something again and again. There were 4 instances of children trying something again and again. In each case, the children attempted to improve their slime over time. For an example of this occurrence, consider the teenager, Jasmine. Jasmine waited in line to make slime with her friend, Daria. See Table 21 for an overview of this interaction.

Table 21.

Jasmine Demonstrating Problem Solving by Trying Again and Again

	Speaker	Utterance	Activity	Image
1	Jasmine:	Is it supposed to look like this?	*Jasmine is making slime when she requests help from Ms. Sarah.*	
2	Ms. Sarah:	Yeah, so the more you mix it, the firmer it gets.	*Jasmine keeps mixing her slime. Her friend, Daria, approaches and peers over her shoulder before moving back.*	
3	Jasmine:	Okay, Daria. I don't know how to do this.	*Jasmine calls her friend, Daria, back over to get feedback about the slime.*	
4	Daria: Jasmine:	Do you give up yet? No, I'm not giving up on this!	*Daria challenges Jasmine, but Jasmine stays in the space to iterate and improve her slime.*	

Chapter VI. Ms. Maggie's Magnetism Station

This finding set focuses attention on Ms. Maggie's magnetism station. The following research questions are answered: (1) How did Ms. Maggie design and facilitate the magnetism station at the Maker Faire? and (2) What indicators of learning were observable among children who visited the magnetism station at the Maker Faire?

Design of Station

Ms. Maggie's group of three TCs facilitated a station on magnetism at the Maker Faire. They articulated that the activity was intended to meet five *NGSS* performance expectations spanning elementary school, depending on the age of the child (see Table 22). Additionally, during her pre-interview, Ms. Maggie described how she hoped children would "understand where [magnets] are in the real world in a more scientific sense. Where [magnets] come from…that it's a force, a field that repels and attracts. [Magnets] can do some cool thing, but [they're] also used for electricity."

Table 22.

NGSS Performance Expectations for the Magnetism Station

K-2-ETS1-1	Ask questions, make observations, and gather information about a situation people want to change to define a simple problem that can be solved through the development of a new or improved object or tool.
2-PS1-3	Make observations to construct an evidence-based account of how an object made of a small set of pieces can be disassembled and made into a new object.
3-PS2-1	Plan and conduct an investigation to provide evidence of the effects of balanced and unbalanced forces on the motion of an object.
3-PS2-3	Ask questions to determine cause and effect relationships of electric or magnetic interactions between two objects not in contact with each other.
4-PS3-2	Make observations to provide evidence that energy can be transferred from place to place by sound, light, heat, and electric currents.

The overarching question for Ms. Maggie's station was, "How do magnets work?" Her group designed a series of five mini-activities that children could visit in any order (see Figure 26). Interestingly, she noted that "materials will be arranged in order from most passive/introductory to most involved," and the mini-activities were "designed to be free flowing, and involve differentiation to allow for choice," so children could visit the mini-activities in any order. Ms. Maggie's group also provided smaller questions or challenges for each mini-activity. For example, "Can you make a spinning motor with only a battery, wire, and magnet?" was a challenge posed at the homopolar motor activity. See Figure 25 for an image of Ms. Maggie's magnetism station and Figure 26 for a graphical representation. Following, each mini-activity is described briefly for additional context.

Figure 25. Ms. Maggie's magnetism station at the Maker Faire.

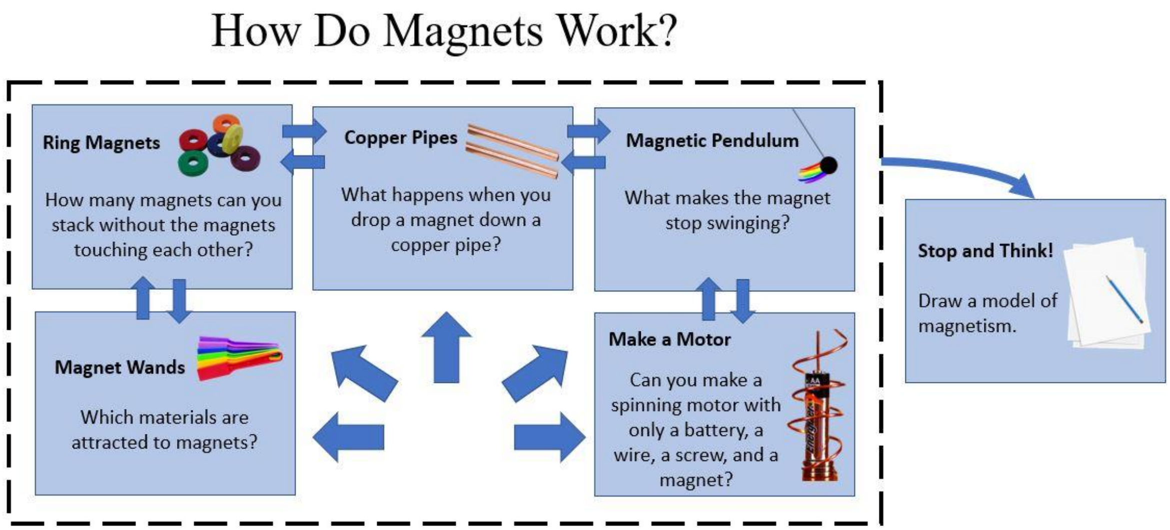


Figure 26. Graphic representation of Ms. Maggie's magnetism station.

The first activity featured ring magnets that children were challenged to make hover, without touching, along a circular rod secured to a base (see Figure 27). Like a refrigerator magnet, only one side of each ring magnet was ferromagnetic, or demonstrated magnetic properties. To complete the challenge, children had to intentionally place each ring magnet on the circular rod in the correct orientation (repelling instead of attracting) to achieve the hovering effect.

Figure 27. Ms. Beth working with two boys and the ring magnet activity.

The second activity featured “magnet wands” that children could wave over a tray of random materials. The magnet wand caused ferromagnetic materials to stick (or attract). This allowed children to begin developing models to account for magnetic interactions. Often, these beginning models showed all metals attracting to magnets. However, Ms. Maggie and her group members intentionally included *pennies* in the magnet wand activity to challenge this potential model. Pennies are made of copper, a non-ferromagnetic metal. That is, they are metal but do not stick to magnets.

Two other activities at the magnetism station provided opportunities for children to experiment with copper in different contexts. First, children could drop a magnet down copper pipes of varying diameters to observe an eddy current phenomenon: as the magnet moves through the copper pipe, it induces an electric current in the copper. These currents create their own magnetic field, which opposes (or repels) the magnet falling through the copper pipe, causing the motion of the magnet to slow beyond what one would expect. Second, children could swing a magnet attached to the end of a pendulum over copper plates, experiencing the eddy current phenomenon in a different manner.

The final activity, facilitated by TCs due to safety concerns, was creating an electric (or homopolar) motor using a battery, magnet, nail, and wire. As shown in Figure 28, the TCs created a homopolar motor by attaching a nail and magnet to the bottom of a battery. They used a wire to complete the circuit, connecting the bottom of the magnet to the top of the battery. This created an electric current, which caused the nail and magnet to spin noticeably.

Figure 28. Ms. Peggy showing a child the homopolar motor.

In addition to the five mini-activities featured at the magnetism station, there was also a designated "stop and think" area where children could draw models of what they thought was occurring with the magnets (see Figure 29). Ms. Maggie thought this served two purposes. First, this provided opportunities for children to reflect on their initial understandings. Second, this provided opportunities for Ms. Maggie to assess their initial understandings.

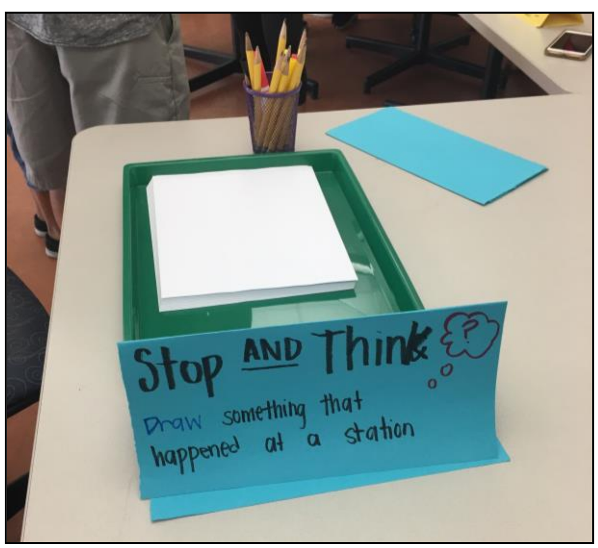


Figure 29. The "stop and think" area of the magnetism station.

Facilitation Techniques

This section focuses on Ms. Maggie's facilitation techniques while at the magnetism station. She wore the point-of-view camera during the event. I begin this section with an illustrative vignette that depicts common facilitation techniques used by Ms. Maggie at the magnetism station.

Vignette: You want to play here?

Evan, a sixth-grade student in Ms. Maggie's student-teaching classroom, entered the room. Ms. Maggie immediately noticed and walked over to greet him.

Ms. Maggie: Evan! I'm so happy you're here! Do you want to visit my magnet station?

Evan eagerly nodded his head "yes." Ms. Maggie and Evan walked over to the magnetism station, followed closely behind by Evan's parents and younger brother, Max. When they reached the station, Ms. Maggie greeted the remaining members of Evan's family.

Ms. Maggie: How you doing?

Mom: Alright.

Ms. Maggie: Is this younger brother?

Mom: Yes, this is Max.

Just then, another TC in the group, Ms. Beth, gently touched Max on his wrist.

Ms. Beth: Were you in Ms. Goodman's class play last year?

Max's eyes lit up. He was surprised, but excited. He responded, "Yeah," with a smile.

Ms. Beth: I've seen your video! I'm [a student teacher] in her class this year. We're getting ready for our rehearsal and we've been watching you. We watched yours to get ready for our play.

Mom: You're famous!

Max: I know! And, we watched –

Ms. Beth: - you watched the year before? Yeah! We're watching you, so we know what to do when it's our turn. You're famous.

Max seemed thrilled to be remembered. Meanwhile, his older brother, Evan, had already started playing with the ring magnet activity. Ms. Maggie shifted the conversation with Max back to the magnetism station.

Ms. Maggie: Alright. You want to play here?

Max: Yeah.

Ms. Maggie: Come on in here.

Max approached the magnet sort area, where Evan rejoined him.

Ms. Maggie: Alright. So, take this [magnet wand]. I want you guys to find out what sticks, what doesn't stick. What's magnetic? What's not magnetic? Sort them into two piles.

Ethan and Max immediately began hovering their magnet wands over the miscellaneous materials in the tray. They continued sorting objects with the help of Ms. Maggie, who occasionally introduced a new item ("Does the rock stick?"; "What about the paperclip?"). Eventually, all the objects were sorted.

Evan: I don't see anything else.

Ms. Maggie: So, it doesn't really seem like the pennies are sticking. Do you know what pennies are made of?

Max: Copper.

Evan: Copper.

Ms. Maggie: Yeah. They're made out of copper. Right now, copper is not sticking. Let me take you to another [activity] here. Come on over here.

The above vignette depicts common facilitation techniques observed at the magnetism station. First, Ms. Maggie offered an explicit invitation to engage with her station, and personally introduced herself to the members of Evan's family. Further, Ms. Beth made a personal connection to Max about his role in the class play, seemingly increasing his motivation to engage at the station. Ms. Maggie used direct instruction briefly (to explain the goal of the activity: to sort objects into two piles based on magnetic properties). After, she asked questions, introduced new materials, and re-voiced the boys' responses as they worked to sort objects. Finally, when the boys discovered that copper was a type of metal that did not stick to the magnet wands, she transitioned them to a new activity to continue testing and complexifying their thinking about magnetism.

See Figure 30 for an overview of Ms. Maggie's facilitation techniques used at the magnetism station. Following, each technique is described through illustrative examples. Facilitation techniques are discussed in order of most common to least common occurrence. Unobserved facilitation techniques are not discussed.

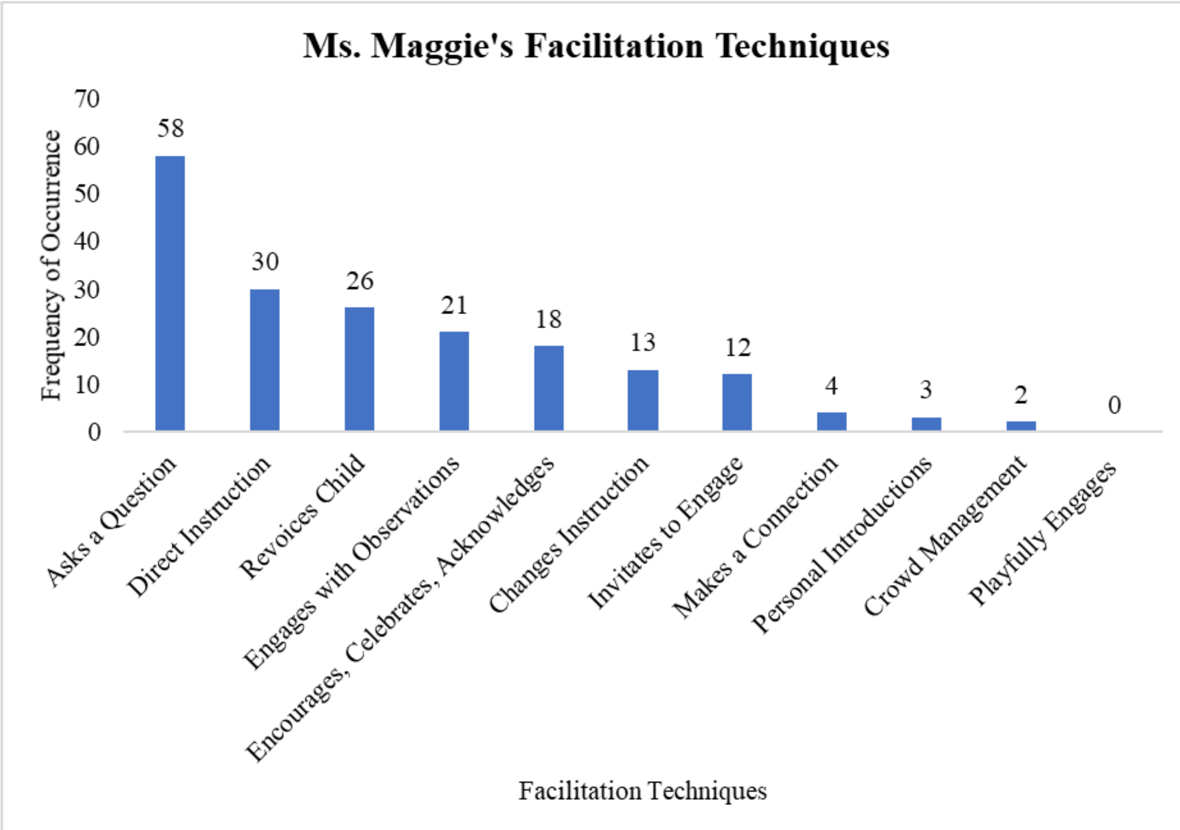


Figure 30. Ms. Maggie's facilitation techniques at the magnetism station.

Asking questions. Ms. Maggie's main facilitation technique was asking questions. During the event, Ms. Maggie asked a total of 58 questions (representing 31% of her facilitation techniques). Ms. Maggie's questions broadly fell into three main categories: related to content, materials, and other (see Table 23).

Nearly three quarters (74%) of Ms. Maggie's questions were related to the content. The questions Ms. Maggie asked about content fell into two main categories: (a) making predictions about what would happen in an experiment, and (b) constructing explanations to describe observations after conducting an experiment. In both cases, children were engaged in explaining their thinking related to the mini-experiments conducted at the magnetism station. For example, before conducting the eddy current experiment, Ms. Maggie frequently asked children, "What do you think will happen if we drop this magnet down the copper pipe?" After conducting the experiment, Ms. Maggie often asked, "What happened?" or "What did you notice?"

Table 23.

Types of Questions Asked by Ms. Maggie

Type of Question	**Examples**	**Count**	**Percent**
Related to content		43	74%
	Constructing Explanations What happened? What are you noticing?	(35)	(60%)
	Making Predictions What do you think will happen to the magnet? If we put this copper under [the pendulum], what do you think will happen?	(8)	(14%)
Related to materials	"Do you want to swing the [pendulum]? "Do you want to keep playing with that [magnet wand]"?	10	17%
Other	Have you been to any other stations? What did you say?	5	9%

Ms. Maggie asked fewer explicit questions about materials (17%). In most cases, Ms. Maggie's questions about materials were connected to the material properties. For instance, Ms. Maggie often asked children if they knew what material pennies were made from. In other cases, Ms. Maggie's questions about materials were to ensure children had the correct materials to engage in the experiments at the magnetism station. For example, she asked one child, "You don't have a [magnet wand]?" before handing him a magnet want to sort objects into piles based on the property of non-magnetic versus magnetic.

Finally, a smaller percentage (9%) of Ms. Maggie's questions were classified as "other" because they did not relate to content or materials explicitly. For example, Ms. Maggie occasionally asked a child to repeat him or herself when she did not hear the initial response. Other questions classified as "other" were more personal in nature. For instance, when Ms. Maggie greeted a child from her student-teaching placement, she asked if he had visited any other stations at the Maker Faire yet.

Direct instruction. The next most common facilitation technique used by Ms. Maggie was direct instruction. There were 30 instances of Ms. Maggie directly instructing a child at the magnetism station (representing 17% of her overall facilitation techniques). In most of these cases, Ms. Maggie's direct instructions were connected to the experiments. Consider the following direct instruction given to a child by Ms. Maggie:

> *And, what I want you to do is just wave [the magnet wand] over and make two piles, one that's sticky and one that's not sticky. Tell me what is sticky, what is not sticky. See what's magnetic, what's not magnetic.*

In the above quote, Ms. Maggie was informing the child about how to engage with the activity (i.e., sorting objects into two piles based on magnetic properties). Additionally, Ms. Maggie occasionally offered follow-up prompts, such as "Put that in the stick pile," to ensure a child was sorting objects correctly.

Similarly, Ms. Maggie offered instructions about setting up the eddy current and magnetic pendulum experiments. For example, she said the following to one child before they engaged in the magnetic pendulum experiment: "Here's what I want you to do. I want you to swing that magnet [on the pendulum]. Give it a big swing!" This was another example of direct instruction provided by Ms. Maggie to help children engage in the experiments at the magnetism station. Additionally, Ms. Maggie sometimes instructed children to "do it again," or "try it again," about swinging the pendulum or dropping the magnet down the copper pipe. In these instances, Ms. Maggie seemed to also encourage risk-taking and experimentation by instructing the children to repeat certain crucial experiments.

Aside from providing direct instructions related to experimental design, Ms. Maggie sometimes offered instruction about materials. It was common for Ms. Maggie to help new children get oriented to the materials at the station. Ms. Maggie's instructions, such as "That's a magnet," or "That's a magnet wand," were also classified as direct instruction.

Finally, Ms. Maggie also directly instructed some children about *content*. Usually these occurrences also involved her asking questions. For example, consider the following:

> *So, when I drop the magnet, in real life, like without the pipe, it just drops, right? Like, how you would expect it to. But, what's different about dropping it down the pipe?...Why is it going slower?*

In the above quote, Ms. Maggie was directly explaining an important result of the experiment: When the magnet was dropped down the copper pipe, it moved more slowly than it did when dropped *outside* of the pipe ("like in real life"). She informed the children of this observation, as if to ensure there was a common understanding, before asking a new question ("Why is it going slower?"). Ms. Maggie did this several times throughout the event. By introducing some common understanding – through direct instruction – she was able to ask additional questions to elicit children's thinking about the experiment. The scientific explanation of this is that as the magnet moves through the copper pipe, it induces an electric current in the copper. These currents create their own magnetic field, which opposes (or repels) the magnet falling through the copper pipe. This phenomenon slows the falling magnet. This explanation is beyond what one would expect an elementary school student to develop, but the TCs thought it was an interesting (and surprising) magnetic phenomenon that children could observe to further their thinking about magnetism.

Re-voicing. During the event, Ms. Maggie re-voiced a child's response 26 times (representing 16% of her total facilitation techniques). Most often, Ms. Maggie's re-voicing of children's responses was connected to observations and explanations of content. For example, consider the following exchange with Evan, introduced in the earlier vignette:

Ms. Maggie: You told me copper doesn't stick [to magnets].

Evan: Yeah.

Ms. Maggie: It's true. Copper doesn't stick. So, what do you think will happen to the magnet [if we drop it down a copper pipe]?

Evan: It will fall right through.

Ms. Maggie: You think it will go straight down.

In the exchange above, Ms. Maggie re-voiced Evan's response twice. First, she re-voiced his initial explanation that copper is non-magnetic ("You told me copper doesn't stick"). Second, she re-voiced his prediction that a magnet will fall straight down a copper pipe ("You think it will go straight down"). In both instances, Ms. Maggie was re-voicing Ethan's articulations, seemingly to create a common understanding before conducting another experiment.

Engaging with observations or data. During the event, Ms. Maggie engaged with observations or data 21 times (representing 11% of her facilitation techniques). Most often, her articulated observations related to magnetic properties of objects. For example, Ms. Maggie often stated, "That one sticks," or "That's not sticking," to describe results of the magnet sort activity. Further, Ms. Maggie referenced the observation that copper was not sticking to metal multiple times throughout the event. Additionally, for the pendulum activity, Ms. Maggie often shared observations about the speed in which children swung the pendulum (fast or slow). Similarly, Ms. Maggie made observations about the speed of the magnet moving down the copper pipe (fast or slow). It is worth noting that in the case of the magnetism station, observations and data were often viewed as one in the same. The speed in which a magnet fell down a copper pipe could be considered an observation of a phenomenon, but it could also be considered "data" collected from the experiment, if done in a systemized manner. Most often, Ms. Maggie's articulations were observations, but could easily be transformed into data in a well-monitored experiment.

Encourages, celebrates, acknowledges. Ms. Maggie explicitly *encouraged* risk-taking and experimentation 13 times throughout the event. This encouragement often came when Ms. Maggie facilitated the eddy current and pendulum activities at the magnetism station. Recall the exchange between Ms. Maggie and Evan depicted in the earlier vignette. Evan was working to make sense of the eddy current activity alongside his younger brother, Max. After Evan shared his initial hypothesis (the magnet will fall straight down the copper pipe), Ms. Maggie pushed him to explain his thinking and encouraged him to experiment. The following exchange occurred:

Ms. Maggie: It's true. Copper doesn't stick. So, what will happen to the magnet?

Evan: It will fall straight through.

Ms. Maggie: You think it will fall straight down. So, you think it will go like that fast (*drops magnet in mid-air, catches with her hand*)?

Evan: Uhhhh….maybe.

Ms. Maggie: Maybe. Why are you not sure?

Evan: Because they're both metal.

Ms. Maggie: They're both metal.

Evan: Well, yeah….

Ms. Maggie: Do you want to do some testing?

Evan: Yeah.

Ms. Maggie: Okay, I'm going to hold this [copper pipe]. I want you to drop this [magnet].

Max: I want to do it!

Ms. Maggie: You want to drop it?

Evan: Here (*hands Max the magnet*).

Ms. Maggie: I've got two pipes, so we can do it twice.

(*Max drops magnet down pipe*)

Ms. Maggie: Do it again. Do it again.

In the above exchange, Ms. Maggie encouraged risk-taking and experimentation several times. First, when Evan was unable to justify his response, she pushed him to experiment with the copper pipes. Second, she also encouraged Max to experiment ("I've got two pipes, so we can do it twice."). Finally, she encouraged the boys to repeat the experiment several times ("Do it again. Do it again."). This was an example of how Ms. Maggie encouraged risk-taking at the event. See Figure 31 for an image of Max dropping the magnet down the second copper pipe.

Figure 31. Max dropping the magnet down the copper pipe.

Ms. Maggie also *acknowledged* moments of frustration among children visiting the station. This occurred 4 times throughout the event. For an example, consider one sixth grade girl from Ms. Maggie's student-teaaching classroom named Sulema. Sulema stayed at the magnetism station for an extended period (21 minutes compared to the average of 9 minutes). During this time, she participated in all the activities the station offered. When working to understand the pendulum activity, the following exchange occurred between Sulema, Ms. Maggie, and another TC, Ms. Peggy.

Sulema: This is so difficult.

Ms. Maggie: It's so difficult? What's difficult? We're just playing.

Ms. Peggy: Oh! Magnets are difficult. I totally agree with you.

Ms. Maggie: They're definitely not easy.

Ms. Peggy: Because you can't see what's happening, right?

Sulema: Uh huh.

The exchange above represented a moment when Ms. Maggie (accompanied by Ms. Peggy, in this case) acknowledged Sulema's moment of frustration or confusion ("This is so difficult"). Further, they justified Sulema's expression ("Because you can't see what's happening, right?). This seemingly gave permission to Sulema that it was okay to not immediately understand something. Sulema stayed at the magnetism station for another 10 minutes after this exchange, signaling she felt comfortable and supported enough to stay and continue engaging in the activities.

Figure 32. Sulema after stating, “This is so difficult.”

Finally, Ms. Maggie expressly *celebrated* another student from her sixth-grade placement classroom who visited the magnetism station – Kayla. The following exchange represents a moment when Ms. Maggie celebrated what a child was doing (in this case, simply visiting her station).

Ms. Maggie: Have you been to any other stations?

(*Kayla shakes her head, “no”)*

Ms. Maggie: This is your first one?

(*Kayla shakes her head, “yes’*)

Ms. Maggie: Oh! I’m so happy you came to me first!

In this case, Ms. Maggie celebrated that Kayla came to her station before visiting others at the Maker Faire. Ms. Maggie’s tone of voice and smile during this exchange provided further evidence of the celebratory nature of this exchange.

Changing instruction. Ms. Maggie changed her instruction based on children's ideas 13 times throughout the event (representing 7% of her total facilitation techniques). She typically offered changes in (a) materials or (b) activities. The design of the magnetism station allowed Ms. Maggie to easily make these changes. For instance, at the magnet sort activity, Ms. Maggie would offer new *materials* for children to test with their magnet wands. Recall the goal of the magnet sort activity was to sort objects into two piles, one magnetic and the other non-magnetic. Most often, children visiting this station inherently discovered that metal objects had magnetic properties. When a child articulated this realization, it prompted Ms. Maggie to provide a new material: the penny. Pennies are made from copper, a type of metal, but are not ferromagnetic. That is, they are not attracted to a magnet. Introducing a new material (in this case, a penny) prompted children to confront their own working hypotheses (metal is magnetic) with a discrepant event (copper is a metal, but not magnetic). This small change in instruction allowed for moments of cognitive dissonance to occur, possibly leading to more nuanced understandings of magnetism.

Further, because the magnetism station had a series of small activities, Ms. Maggie was able to change her instruction when she noticed a child was ready to move on to something new. The following exchange from the earlier vignette represents a common transition that Ms. Maggie helped children make after completing the magnet sort activity:

Ms. Maggie: So, it doesn't really seem like the pennies are sticking. Do you know what pennies are made of?

Max: Copper.

Evan: Copper.

Ms. Maggie: Yeah, they're made out of copper. Right now, copper is not sticking. Let me take you to another station. Come on over.

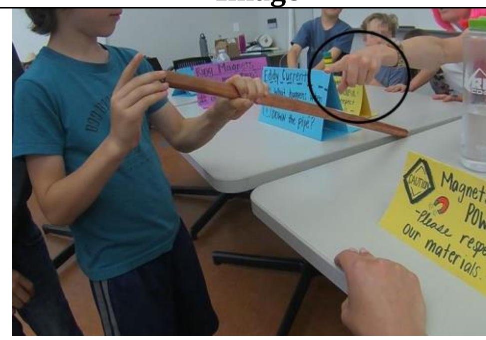
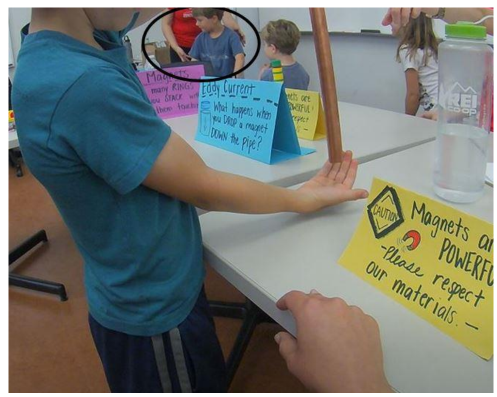
Ms. Maggie then walked the boys over to the magnetic pendulum activity, where they experimented with copper and magnets in a different context. This purposeful change in instruction allowed children to build on their working models, slowly collecting new evidence from the activities presented at the magnetism station.

Invitations. Ms. Maggie explicitly invited 12 children to engage at the Maker Faire (representing 6% of her total facilitation techniques). Sometimes these invitations were to the whole station. For example, Ms. Maggie greeted one student from her practicum classroom with, "Do you want to visit my magnet station?" In another interaction, Ms. Maggie noticed a young boy approaching the magnet sort activity, which prompted her to ask, "You want to play here?" Both examples were considered an explicit invitation to the station. Additionally, Ms. Maggie often invited children into the physical space. Due to the way in which the magnetism station was arranged, it was sometimes difficult to see a phenomenon of importance (i.e., dropping the magnet down the copper pipe). This arrangement seemingly caused Ms. Maggie and her group members to offer explicit invitations into the space more often. For example, consider the interaction depicted in Table 24.

Ms. Maggie was working with Evan and Max on the eddy current activity when she noticed that two additional boys working with Ms. Peggy were also ready to engage in the eddy current activity. This caused Ms. Peggy and Ms. Beth to help walk the new children over to Ms. Maggie. During this time, Ms. Maggie articulated several verbal invitations into the space before eventually conducting the eddy current activity with all four children present.

Table 24.

Ms. Maggie Inviting Children into the Space

	Speaker	Utterance	Activity	Image
1	Ms. Maggie:	Come on over. Come on over.	*Ms. Peggy points to where the children should walk next, as Ms. Maggie verbally invites them into the space.*	
2	Ms. Maggie:	Come on over. Let's take a look at what's going on.	*Ms. Beth helps the children walk over to Ms. Maggie.*	
3	Ms. Maggie:	Come here.	*Ms. Maggie re-positions the pipe so all four boys can see. She hands a magnet to a new arrival to test.*	

Making connections. During the event, Ms. Maggie made 4 connections. In three of these cases, the connections were to other activities at the magnetism station. For example, before helping children engage with the eddy current activity, she asked, "What did we learn from the other one? Let's recap real quick." This prompted the children to recall that metal is magnetic, except for copper, before experimenting with copper pipes. Similarly, before engaging children in the pendulum activity, Ms. Maggie asked, “What happened when we were playing with the pipes?” In both instances, Ms. Maggie articulated connections between activities at the magnetism station, seemingly to help children see the connections themselves, refining their mental models of magnetism over time through increased engagement at the station.

Ms. Maggie also made personal connections to children at the Maker Faire. Recall Sulema, a sixth-grade student from her student-teaching classroom. When Ms. Maggie noticed Sulema enter the room where the magnetism station was located, Ms. Maggie immediately walked away from the station and greeted her. During this time, Ms. Maggie asked Sulema about the other stations she had previously visited at the event, admired the kaleidoscope Sulema created, met Sulema’s mother for the first time, and invited Sulema to visit the magnetism station. See Figure 33 for a still image of this interaction.

Figure 33. Ms. Maggie makes a personal connection to Sulema.

Personal introductions. Ms. Maggie personally introduced herself 3 times during the event. One of these examples was depicted in the interaction with Sulema (see Figure 33). Ms. Maggie left the magnetism station to greet Sulema and meet her mother. For another interesting exchange, recall the earlier vignette with Evan and Max. Ms. Maggie knew the older brother, Evan, from her student-teaching placement. However, she did not know Evan’s younger brother, Max. The following exchange occurred:

Ms. Maggie: Evan! I’m so happy you’re here! Do you want to do my magnet station?

Evan: Yeah.

(*Evan’s mom and younger brother, Max, approach the station*)

Ms. Maggie: How you doing?

Mom: Alright.

Ms. Maggie: Is this younger brother?

Mom: Yes, this is Max.

This personal introduction allowed Max access into the space that only Evan had previously occupied. See Figure 34 for a still image of this interaction.

Figure 34. Ms. Maggie greeting Max.

Crowd management. Ms. Maggie only explicitly engaged in crowd management twice during the event. In one instance, Ms. Maggie prompted a child to help her clean up the magnet sort activity so that it was “good for the next person.” This was considered an instance of crowd management because she organized materials in anticipation of the next arrival. Another instance of Ms. Maggie engaging in crowd management occurred in Table 24. Recall Ms. Maggie was facilitating the eddy current activity for four children simultaneously. This prompted her to take the pipe from a child, stating, “Let me see that pipe. Here, put it down here so you can see. I want you to be able to see down it.” In this instance, Ms. Maggie took a copper pipe away from a child so that other children could also observe the magnet moving down the pipe. These were both instances of crowd management at the magnetism station.

Indicators of Learning

In this section, I describe indicators of learning observed at the magnetism station. As was the case for the slime station, it is important to note that all episodes from the magnetism station were included in the analysis for this section (not just the episodes where Ms. Maggie was facilitating individually). Due to the placement of the cameras, Ms. Maggie occasionally captured her group members on film facilitating at the event or co-facilitated an activity with her group members. Thus, all children who visited the magnetism station and were captured on video are included in this analysis.

Over the course of the event, 35 children visited the magnetism station. On average, children stayed for 9 minutes and 7 seconds. The shortest amount of time a child stayed was 1 minute and 14 seconds. The longest amount of time a child stayed was 21 minutes and 30 seconds. Due to the placement of the cameras, however, some interactions that occurred between Ms. Beth or Ms. Peggy and children were not clearly captured on film. These interactions, occurring in the background of the collected video with poor audio, were not included in the analysis for indicators of learning. Instead, 22 children who were clearly captured on film are included in this analysis.

Figure 35 shows the frequency of occurrence of the five indicators of learning described in the Chapter 3 across the 22 children. Overall, of the indicators coded for, children visiting the magnetism station demonstrated *conceptual understanding* roughly twice as many times as any other indicator. The next most frequent indicator of learning was *creativity and self-expression,* followed closely by *initiative and intentionality*. Finally, the children at the magnetism station demonstrated fewer indicators, yet equal amounts, of *problem-solving and critical thinking* and *social and emotional engagement*. Each of these areas are described in more detail below (from highest frequency of occurrence to lowest) using illustrative vignettes.

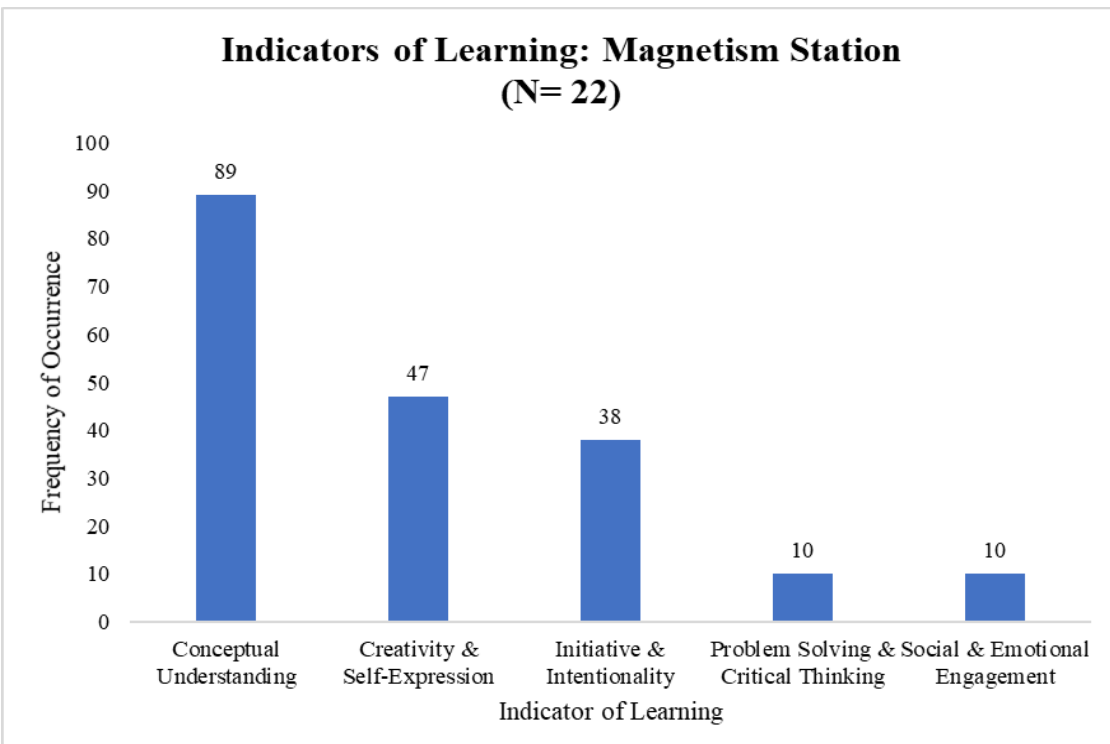


Figure 35. Indicators of learning observed among children at the magnetism station.

Conceptual understanding. There were 89 instances of children demonstrating *conceptual understanding* while at the magnetism station (see Table 25).

Table 25.

Indicators for Conceptual Understanding at the Magnetism Station

Indicator of Conceptual Understanding	Frequency of Occurrence
Constructs verbal explanation	79
Controls for or attends to variables	5
Expresses an "aha" moment	4
Uses analogies or metaphors to explain	1
Sum	89

Constructing verbal explanations. Most children demonstrated conceptual understanding by *constructing verbal explanations*. Among the 22 children who visited the magnetism station, 79 verbal explanations were constructed (an average of nearly 3 verbal explanations per child). The explanations that children constructed fell into three main categories: (a) *summarizing results* from previous investigations, (b) *sharing predictions* before an investigation, or (c) *describing results* after an investigation. Consider the following interaction that occurred when Ms. Maggie and Ms. Peggy facilitated the pendulum activity with Evan and two other boys, Jared and Jason, for an example of each type of explanation (see Figure 36).

Figure 36. Children engaging in the magnetic pendulum activity at the magnetism station.

In the image above, the group of three boys was preparing to begin the pendulum activity after learning about eddy currents by dropping a magnet down copper pipes. Before the investigation began, Ms. Peggy prompted the boys to stop and reflect on what they learned from the last activity:

Ms. Peggy: What did we learn from that other [eddy current activity] though?

Ms. Maggie: Let's recap real quick.

Jared: The closer [the magnet] is to [the copper pipe], the easier it is to grab the [magnet].

Ms. Maggie: Okay.

Ms. Peggy: What did *you* notice about the eddy current, the tube (*points to Evan*)? Did [the magnet] go faster or slower?

Evan: Slower when [the pipe] was bigger. No, wait. Faster.

Ms. Maggie: Faster when the pipe was bigger?

Jared: And slower when it's small.

The above exchange represents an example of the boys constructing explanations to summarize the results of their last investigation. In this case, Jared and Ethan constructed the shared understanding that the magnet moved down the larger copper pipe *faster* than it did the smaller copper pipe. This also fit with Jared's initial explanation that that closer the magnet is to the copper pipe, the easier it is for the copper to "grab" the magnet, slowing its motion. From here, the boys articulated predictions about the next activity:

Ms. Maggie: Now, let's make a little experiment. If we put this copper under [the magnet attached to the pendulum], what do you think will happen?

Ms. Peggy: Remember [copper] doesn't stick to [the magnet], but what could happen if the [copper] is near [the magnet]?

Evan: It could repel it.

Jared: [The magnet] is going to pull [the copper] up, so it's heavier and it can't go anywhere.

Ms. Peggy: So, repel it (*points to Ethan*), pull it (*points to Jared*). What do you think (*points to Jason*?)

Jason: I don't know.

Ms. Peggy: You're not sure? That's fine.

Jason: I think it's not going to go as long.

Ms. Peggy: It's not going to go as long?

Evan: Wait! It might go longer because it went longer but slower [with the copper pipe activity].

Ms. Peggy: Longer, but slower. So, maybe it will go –slower or faster here?

Evan: Slower.

Ms. Peggy: Slower with the copper? Okay.

Ms. Maggie: Okay. Swing it. Let's try it.

Again, the boys shared various predictions about what they expected to happen with the magnetic pendulum. Ms. Peggy ensured each child shared a prediction before the group began the experiment. After sharing predictions, the boys tested the pendulum. During their test, they observed the pendulum's motion slow as it met the copper plates situated underneath. The pendulum swung for less overall time than it did without the copper situated underneath. They constructed explanations to make sense of the results.

Ms. Peggy: What just happened?

Jason: It was getting faster, but then it got slower instead.

Jared: It's going faster, then slower.

Evan: It goes slower for a littler amount of time.

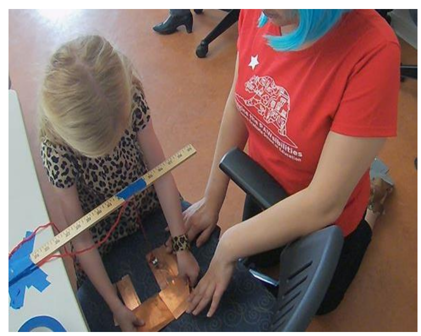
As shown above, the boys reached a consensus that the copper plates situated underneath the magnetic pendulum indeed slowed the pendulum's motion. All the above examples demonstrated different types of verbal explanations constructed by children at the magnetism station.

Controls for, or attends to, variables. There were 5 instances of children controlling, or attending to, variables while at the magnetism station; three of these instances occurred with the same first-grade child, Gabby. After the eddy current activity, Gabby moved onto the pendulum activity. See Table 26 for an overview of how Gabby attended to variables.

Gabby attended to variables three distinct times while engaging in the pendulum activity. First, she checked to see if either side of the copper plate was magnetic. Second, she ensured the copper plates were positioned appropriately before testing. And, third, Gabby attended to the speed in which she swung the pendulum.

Table 26.

Gabby Attending to Variables at the Magnetism Station

	Speaker	Utterance	Activity	Image
1	Ms. Beth:	And, this is just a big old stick of copper. Do you want to test to see if it sticks?	*Ms. Beth helps orient Gabby to the pendulum activity, holding up a stick of copper and inviting her to engage.*	
2	Gabby: Ms. Beth:	Nope. Neither side. Do you want to swing it and see what happens?	*Gabby tests to see if the copper stick is magnetic. She checks both sides. Ms. Beth invites her to swing the pendulum.*	
3	Gabby:	Wait. What if we…I just want to make this flat.	*Gabby attends to the copper plates, ensuring each is laid down flatly to avoid interfering with the reliability of the experiment.*	
4	Gabby:	Now, I’m going to do it pretty fast.	*Gabby attends to the speed in which she swings the pendulum. She swings the pendulum harder than she observed the teacher do so earlier.*	

	Speaker	Utterance	Activity	Image
5	Gabby:	It was supposed to go pretty fast, but it slowed down.	*Gabby observes the pendulum's motion before articulating that her expectation was not met. Ms. Peggy (off camera) helps Gabby make a connection to the copper pipe activity.*	
	Ms. Peggy:	Well, didn't you say it slowed down [with the copper pipe] too?		

Expresses an "aha" moment. There were 4 instances of children expressing an "aha" moment while at the magnetism station. Each of these "aha" moments varied based on the age of the child and the activity in which they engaged. For an example of an "aha" moment, recall Sulema. Sulema was a sixth-grade student in Ms. Maggie's student-teaching classroom. She also expressed that the magnetism station was "difficult" several times, perhaps making her "aha" moment more significant. When working with Sulema and a group of children to make a motor using a magnet, Ms. Peggy prompted them to reflect on what might be causing the motor's motion. Initially, Ms. Peggy's question elicited no response from the children, until Sulema raised her hand (see Figure 37). As she raised her hand, Sulema said, "I know!" with a smile. She added, "I think it's because these things connected to the battery, and the electricity is making that move fast." Sulema was correct. The wires connecting the battery to the magnet did allow electricity to flow, causing the motion that Sulema observed. Before this interaction, Sulema had spent roughly 20 minutes at the magnetism station (much longer than the average of 9 minutes), working to complexify her ideas over time. This moment was significant because it represented the culmination of Sulema's participation and understanding at the magnetism station. Further, the event ended just a few minutes after this interaction.

Figure 37. Sulema expressing an "aha" moment while at the magnetism station.

Uses analogies or metaphors to explain. There was only 1 instance of a child using an analogy or metaphor to explain her thinking at the magnetism station. Again, it was Sulema while working with Ms. Peggy to make a motor. When the motor began noticeably spinning, the children observing became excited. A collaborative "woah!" erupted from the group. Following, Sulema shared her analogy, "It's running very fast." In this instance, Sulema created an analogy between a human running and a motor's motion to help her explain what she observed. While it is not uncommon for someone to reference a motor running (e.g., "Is that car's motor running?"), there was evidence in this interaction that Sulema was not aware of this connection, further justifying her remark as a metaphor or analogy. Earlier in this exchange, Sulema explicitly asked Ms. Peggy what a motor was, indicating she did not have much prior experience with this idea. Further, Sulema made motions that indicated her connection to a person running. As shown in Figure 38, Sulema shook her head around and flailed her arms (arrow included to indicate motion). This was the only instance of a child creating an analogy or metaphor to explain a scientific phenomenon while at the magnetism station.

Figure 38. Sulema sharing an analogy to explain the motor.

Creativity and self-expression. The next most frequent indicator of learning observed among children at the magnetism station was creativity and self-expression. See Table 27 for the sub-codes under this indicator of learning, followed by examples.

Table 27.

Indicators for Creativity and Self-Expression at the Magnetism Station

Indicator of Creativity & Self-Expression	Frequency of Occurrence
Expresses emotion	16
Playfully explores	11
Makes a connection	9
Challenges or disagrees with someone's idea	7
Uses materials in novel ways	4
Sum	47

Expresses emotion. There were 16 instances of children expressing emotion at the magnetism station, one indicator of creativity and self-expression. The range of emotions coded for included: joy and excitement (7 instances), frustration and disappointment (4 instances), surprise (4 instances), and pride (2 instances). Children most often *expressed joy and excitement* when playing with the magnet wands or the ring magnet stacking activity. Both activities were less teacher guided than others and involved more unstructured play time. Children expressed *frustration or disappointment* about not being able to understand something; for instance, recall Sulema's articulation, "This is so difficult" when she struggled to explain the pendulum activity. Most instances of a child exhibiting *surprise* were evident at the motor activity. When the motor began to spin, children were surprised, as evidenced by raised eyebrows, utterances such as "whoa!", and increased focus (e.g., leaning in) on the task. Finally, there were 2 instances of Sulema demonstrating *pride* at the magnetism station. In each case, she successfully completed some task (such as making ring magnets hover) and articulated her pride: "I did it." For a more complete description of this interaction, see the problem-solving and critical thinking sub-section below.

Playfully explores. There were 11 instances of a child playfully exploring at the magnetism station. Several of these instances were observed with a specific child, Leo. Leo spent a total of 13 minutes at the magnetism station (longer than the average of 9 minutes). Further, he left the station twice and came back to play. Additionally, his excited squeals and animated motion provided evidence for the claim that he was enjoying the activities at the station. See Table 28 for an overview of how Leo playfully engaged.

Table 28.

Leo Playfully Exploring at the Magnetism Station

	Speaker	Utterance	Activity	Image
1	Ms. Beth:	Let's go all the way up here, all the way up here, all the way up here.	*Ms. Beth drops the magnet down the copper pipe, and playfully moves it up and down while waiting for the magnet to reappear. The boys giggle, and playfully push one another.*	
2	Ms. Beth:	See how many you can get to stick on there.	*Leo plays with the ring magnets, attempting to make some hover. Ms. Beth helps, before moving to another group of students.*	
3			*Leo stays to play. His mom leans in and whispers something in his ear. She begins to take his hand, as if trying to leave, but he brushes it away.*	
4			*Leo moves onto the magnet wands. He grabs four wands and tries to get as many items as possible stuck, squealing with excitement.*	

Speaker	Utterance	Activity	Image
5		*Eventually, Leo's mom takes his hand and walks him away from the station.*	

As shown above, Leo playfully engaged at the magnetism station. He rotated through each activity, often squealing with excitement. As further evidence of Leo playfully exploring, he ignored his mother's first request to leave the station. He physically brushed her hand away as she went to grab his wrist. A few minutes later, Leo transitioned to the magnet wand activity where we continued to play. Finally, Leo's mother took hold of Leo's wrist and steered him away from the station. Through all these interactions, it seems reasonable to claim that Leo enjoyed himself at the station and did not want to leave despite his mother's prompting.

Makes connections. There were 9 instances of children making connections to outside, past experiences. Most often, these connections were about materials. For example, the following exchange demonstrates 3 connections that Sulema made while working with Ms. Peggy to make sense of the motor.

Ms. Peggy: Okay, now I want to make a motor.

Sulema: What is a motor?

Ms. Peggy: That's a great question. A motor is something that makes something go.

Sulema: Like in a car?

Ms. Peggy: Absolutely. Like a motor in a car. A motor in a bicycle.

Sulema: A motor in the chair?

Ms. Peggy: Maybe, if it's electric. If it goes. Sometimes you have electric chairs that move. Absolutely.

Sulema: I don't have one.

Ms. Peggy: Me neither. But, they use batteries because they have energy in them.

(…)

Sulema: I have a battery at my house.

In the above exchange, Sulema makes several connections. First, she mentioned a car and chair to further her understanding of items that might have motors. Second, she made a connection to using batteries at her house. All connections indicated that Sulema was connecting new ideas and concepts at the magnetism station to her prior experiences.

Challenges or disagrees with someone's idea. There were 7 instances of a child challenging or disagreeing with someone else's idea. Occasionally, moments of disagreement emerged when children had different predictions about what might happen in an investigation (e.g., dropping the magnet down the copper pipe). Other instances involved a child disagreeing with a TC. For an example, recall Gabby. She attended to variables multiple times while investigating the magnetic pendulum. Before she began investigating the eddy current phenomenon with the copper pipes, the following exchange occurred:

Ms. Beth: This is a copper pipe. Pennies are also made out of copper.

Gabby: But, copper doesn't stick!

Gabby emphatically challenged the TC in this moment. Before Ms. Beth even finished reviewing the materials for this activity, Gabby vocalized her understanding of copper as a non-magnetic metal, which disagreed with Gabby's conceptualization of what was supposed to occur next with the copper pipe activity.

Uses materials in novel ways. There were 4 instances of a child using materials in novel ways at the magnetism station. Two of these instances occurred with the same child, Sophie. In the first case, Sophie was investigating eddy currents using the copper pipes. Unlike any other child, Sophie *shook the pipes* as the magnet moved down slowly. The sound of the magnet hitting the sides of the copper pipe was audible. Further, this provided feedback to Sophie about the interaction between the copper and the magnet. In the second case of Sophie using materials in novel ways, she stuck 14 ring magnets together. This was not the assigned challenge of the activity, but something Sophie decided to do independently. Both uses were novel in that no other child at performed these actions before Sophie at the magnetism station. See Figure 39 for an image of Sophie using materials in novel ways.

Figure 39. Sophie using materials in novel ways.

Initiative and intentionality. The next most frequent indicator of learning observed at the magnetism station was initiative and intentionality. See Table 29 for an overview of the sub-codes, followed by examples of each.

Table 29.

Indicators for Initiative and Intentionality at the Magnetism Station

Indicator of Initiative & Intentionality	Frequency of Occurrence
Takes control of the materials	18
Asks a question	14
Complexifies ideas/goals based on feedback	3
Persists through and learns from failure	0
Repeats a question	0
Sum	38

Takes control of the materials. There were 18 instances of a child taking control of the materials at the magnetism station. It is important to note, that in most cases the child was taking control of materials *from the teacher*. For an example, consider Gabby (see Figure 40). When working to make sense of the eddy current phenomenon, Gabby said, "Wait, let me try!" This prompted Ms. Peggy to hand the magnet to Gabby, who then proceeded to design her own investigation with the copper pipes.

Figure 40. Gabby taking control of materials from Ms. Peggy.

Additionally, there were a few instances of children taking control of materials *from one another*. This seemingly occurred between siblings in each case. For example, recall Evan and his younger brother, Max. When working with the copper pipes, Evan remained in control of the materials for a short amount of time before Max vocalized, “I want to do it.” This prompted Evan to give Max the magnet for testing. See Figure 41 for the magnet trade-off between Evan and Max.

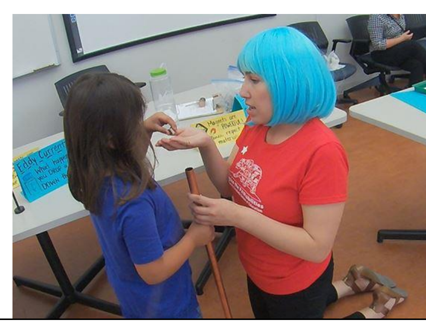
Figure 41. Evan giving Max control of the magnet.

Asking questions. There were 14 explicit questions that children asked while at the magnetism station. In several cases, children asked questions about materials. For instance, one young girl approached the magnetism station, picked up a magnet wand, and asked, “What’s this?” Similarly, when Evan was working with Ms. Maggie at the magnet sort activity, he asked, “What are these big metal things?” Other questions asked by children related to content covered at the station. For example, recall Sulema’s questions related to motors. She asked Ms. Peggy several questions to clarify her conceptual understanding about the connection between electricity and motion. There were no observed instances of children asking one another questions at the magnetism station.

Complexifies ideas/goals based on feedback. There were 3 clear examples of children complexifying their ideas over time based on feedback from people and materials. Consider the following girl, Jane, who worked through several activities with Ms. Beth at the magnetism station. Before beginning, Ms. Beth asked Jane what she knew about magnets. She shared, “They stick together.” See Table 30 for an overview of how Jane’s ideas evolved over time through feedback from materials and people.

Table 30.

Jane Complexifying her Ideas about Magnetism Over Time

	Speaker	**Utterance**	**Activity**	**Image**
1	Ms. Beth: Jane:	That one sticks! Why does that one work? Because it’s metal.	*Jane picks up a silver, metal ring with her magnet wand.*	
2	Ms. Beth: Jane:	Are pennies metal? No.	*Ms. Beth hands Jane a penny. Jane tests the penny with her magnet wand. The penny does not stick.*	
3	Ms. Beth: Jane:	This is a strong magnet. Do magnets stick to copper? No.	*Ms. Beth hands Jane the magnet to test with the copper pipes. Jane takes the magnet.*	

	Speaker	Utterance	Activity	Image
4	Ms. Beth: Jane:	What's happening? It's sticking.	*Ms. Beth and Jane peer into the copper tube to observe the motion of the magnet.*	
5	Ms. Beth: Jane:	What's happening? It's going fast and slow.	*They repeat the experiment on a pipe with a different diameter.*	
6	Ms. Beth: Jane:	What do you think it is about these pipes that's making the magnet do that? Copper makes it stop and stick instead of just going down. It tries to stick.	*Ms. Beth and Jane lean back to discuss the results of their experiment. Each is holding a copper pipe.*	

As shown above, Jane complexified her ideas over time. First, she received feedback from materials at the magnet sort activity, discovering most items that display magnetic properties are metal. Then, Ms. Beth explicitly handed Jane a penny to help her revise her initial mental model of magnetism. Jane immediately tested the penny with the magnet wand, concluding "no," the penny was not metal because it did not stick. From here, Ms. Beth moved Jane along to experiment with the copper pipes. It was in this exchange that

Jane realized the penny and pipes were both made from copper, a type of metal, but neither were magnetic. Next, Ms. Beth and Jane took turns dropping a magnet down copper pipes, testing two pipes of varying diameters. During this investigation, Ms. Beth prompted Jane to describe what she observed twice. Eventually, Jane concluded that the magnet "tries to stick" to copper but was unable to do so (thus, not magnetic). This utterance showed development in Jane's conceptual understanding considering her initial notion that "magnets stick together." She was able to complexify her ideas over time by receiving feedback from materials (e.g., pennies, magnets, copper pipes) and people (i.e., Ms. Beth).

Problem solving and critical thinking. There were 10 instances of children engaging in problem-solving and critical thinking at the magnetism station. See Table 31 for an overview of the sub-codes for problem-solving and critical thinking.

Table 31.

Indicators for Problem Solving & Critical Thinking at the Magnetism Station

Indicator of Problem Solving & Critical Thinking	**Frequency of Occurrence**
Moves from trial and error to focused inquiry	6
Tries something again and again, multiple iterations to troubleshoot	4
Sum	10

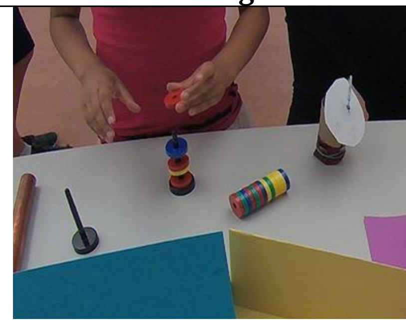
Moves from trial and error to focused inquiry. There were 6 instances of children moving from trial and error to a more focused inquiry. For instance, recall Gabby (see Table 26). Gabby was a first-grade student who took control of materials and attended to variables at the magnetism station. Additionally, Gabby was observed moving from trial and error (playfully waving her magnet wand over items) to a more focused inquiry (carefully attending to variables at the pendulum activity). Other children demonstrating this indicator were like Gabby; they began at the magnet sort activity before moving onto more focused inquiries among the other activities available at the magnetism station.

Tries something again and again, multiple iterations to troubleshoot. There were 4 instances of children trying something again and again (iterating) at the magnetism station. The clearest example of this was observed with Sulema at the ring magnet stacking challenge. See Table 32 for an overview of how Sulema iterated to troubleshoot.

Table 32.

Sulema Trying Something Again and Again at the Magnetism Station

	Speaker	Utterance	Activity	Image
1	Ms. Beth:	See how many you can stack without sticking.	*Ms. Beth reviews the materials and gives Sulema a challenge. Sulema tries to make the ring magnets hover through repulsion*	
2	Ms. Beth:	That still stuck. What can you change?	*Sulema adds the blue magnet, which attracts (not repels). She adds the blue magnet 3 more times, achieving the same result.*	
3	Ms. Beth:	What did you do different?	*She adds a yellow ring, which repels instead of sticking. Ms. Beth grabs the ring magnets from Sulema.*	

	Speaker	Utterance	Activity	Image
4	Sulema:	This is so difficult.	*Sulema keeps adding and removing rings. She attempts to make 5 rings repel and hover. She succeeds in making some rings hover, but not all.*	
5	Ms. Maggie: Sulema:	What happens if you try the other side? It doesn't stick.	*Sulema keeps trying to make the rings hover. She succeeds in stacking 6 rings, but notices there are 2 still stuck together (red and yellow). She removes all the rings and starts over.*	
6	Sulema:	I did it.	*Sulema succeeds in stacking 6 rings, all without touching. She smiles.*	

As shown above, Sulema tried to add ring magnets again and again. In her first attempts, she failed in making the magnets all hover. Through repeated attempts and some guidance offered by Ms. Beth and Ms. Maggie, Sulema eventually succeeded in making 6 ring magnets hover. This interaction occurred over the course of 3 minutes.

Social and emotional engagement. There were 10 instances of children demonstrating social and emotional engagement at the magnetism station (see Table 33).

Table 33.

Indicators for Social & Emotional Engagement at the Magnetism Station

Indicator of Social & Emotional Engagement	**Frequency of Occurrence**
Collaborates and works in a team	7
Teaches another individual	3
Sum	10

Collaborates and works in a team. There were 7 instances of children collaborating in a team. In 6 of these instances, children collaborated in teams with their peers. For example, it was common for children to work together at the magnet sort activity. Consider the brothers Evan and Max shown in Figure 42. They both used their own magnet wand to pull magnetic items out of the tray, into a separate pile.

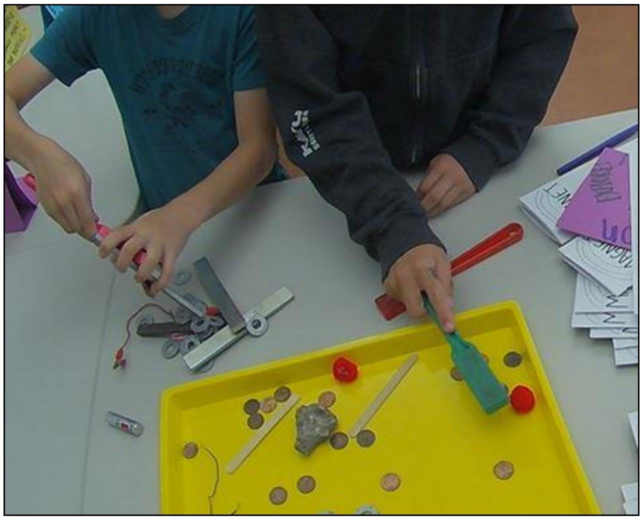


Figure 42. Evan and Max working in a team to sort objects.

Additionally, there was one instance of a child helping a teacher. In this case, Ms. Maggie attempted to pull apart two strong magnets that had accidentally become connected. Sulema, who was working nearby, noticed Ms. Maggie struggling to do so. This prompted Sulema to help Ms. Maggie (see Figure 43). Sulema used a copper plate to slide in between the stuck magnets, allowing Ms. Maggie to separate the two magnets and continue experimenting. This was the only case of a child collaborating with an adult, beyond the designed activities.

Figure 43. Sulema helping Ms. Maggie take apart two strong magnets.

Teaches another individual. There were 3 instances of children teaching another individual at the magnetism station. Two of these instances involved children teaching another *child*. For example, recall when Evan and Max were playing with the copper pipes. Ms. Peggy and Ms. Beth invited two new boys, Jason and Jared, into the space to observe the experiment. As Jared and Jason approached, Max showed the new arrivals what he learned about the copper pipes. He exclaimed, “Watch this! Watch how long it takes to fall!” and proceeded to repeat the experiment for Jason and Jared. This was an example of a child teaching another individual at the magnetism station.

The final instance of a child teaching another individual occurred with Gabby. Rather than Gabby teaching another child, however, she taught her mother. After Gabby observed the eddy current phenomenon using the copper pipes, Ms. Beth prompted her to show her mother, “Why don’t we go show her? Let’s go show her!” Gabby then proceeded to walk with Ms. Beth to her mother and explain what she observed with the copper pipes. See Figure 44 for an image of Gabby teaching her mother.

Figure 44. Gabby teaching her mother about eddy currents.

Chapter VII. Contrasting Stations: Slime vs. Magnetism

This chapter provides a contrastive analysis of the slime and magnetism stations to answer the final research questions: (1) How did the observable indicators of children's learning differ by station? and (2) What salient factors of the station design and facilitation contributed to the differences in children's learning?

How did the observable indicators of children's learning differ by station?

Recall that unequal amounts of children visited the stations, meaning that directly comparing learning indicators based on frequency rates would not lead to a meaningful comparison. Instead, the indicators of learning were averaged across all children who visited the stations, as shown in Figure 45.

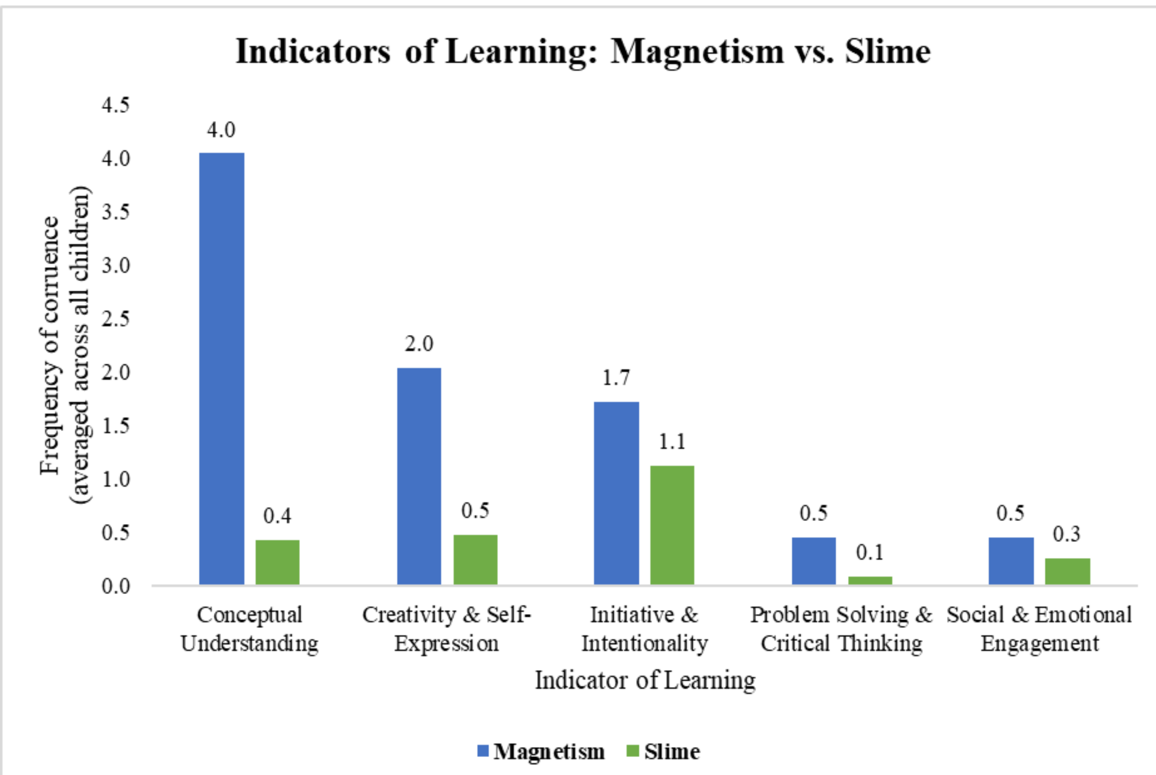


Figure 45. Dimensions of learning by station, averaged across all children, for both stations.

On average, children who visited the magnetism station showed more indicators of learning in *all* learning dimensions when compared to children who visited the slime station. The largest difference was observed in *conceptual understanding*. Children who visited the magnetism station displayed, on average, four instances of conceptual understanding compared to .4 instances at the slime station. One can interpret the .4 instances at the slime station to mean less than half the students who visited the station displayed one instance of conceptual understanding. Similarly, children displayed four times more instances of *creativity and self-expression* at the magnetism station when compared to the slime station. A smaller difference was observed in the learning dimension of *initiative and intentionality*, yet there were still more instances at the magnetism station. Finally, for both stations, the fewest instances of learning were observed for the dimensions of *problem solving and critical thinking* and *social and emotional engagement*; however, in both cases, more instances were observed at the magnetism station.

To determine if these differences were statistically significant, a two-tailed *t*-test was conducted. This *t*-test accounted for unequal group size and unequal variance of learning indicators between the stations. On average, children who visited the magnetism station exhibited more indicators of learning (M = 8.73, SD = 2.47), than those who visited the slime station (M = 2.39, SD = .45). This difference was statistically significant $t(22) = 2.5$, $p = .019$. More learning occurred at the magnetism station than the slime. Despite showing significant differences, however, the *t*-test cannot identify which factors contributed to the differences observed between stations. To help explain these differences, qualitative analysis of the facilitation and activity design are shared through emergent themes in the following subsections.

What factors contributed to this difference in learning?

There were statistically significant differences of the observed learning indicators across the two stations. Since the children's potential for learning is tied to both the activity design and the facilitation strategies, it is important to consider both while also acknowledging that these ideas are not completely independent. That is, the activity design influenced the facilitation strategies.

Differences in station design. Since the station design was planned before the School Maker Faire and, generally, remained unchanged throughout the event, there was no quantitative analysis of the differences in design, only a qualitative analysis. In this section, three themes that epitomize differences in the overall station design are shared.

One pathway vs. many pathways**.** An important distinction between the slime and magnetism stations was in the available pathways to students. The slime station only had one path, an assembly line that children worked through to make their slime (see Figure 46). All children were required to start and end at specific locations. TCs were intentionally positioned along the way to ensure children did not make mistakes.

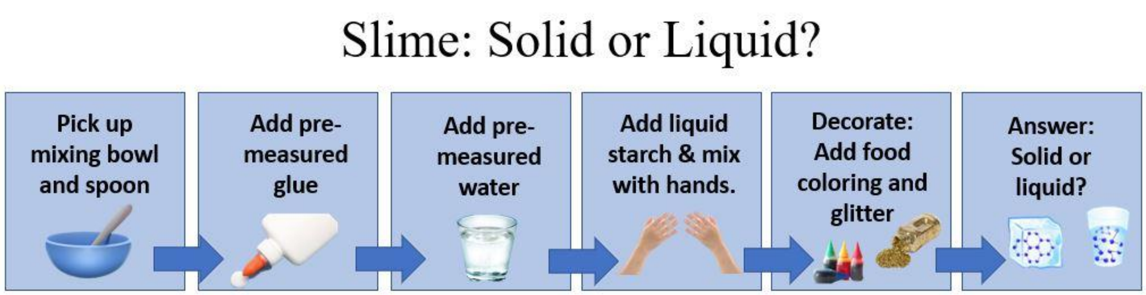


Figure 46. One pathway available to children at the slime station.

In contrast, the magnetism station had multiple pathways available to children (see Figure 47). Children were not required to start with a specific activity or work through a series of rigidly planned activities. Rather, in most cases, TCs greeted children and assessed their initial understandings of magnetism before guiding them towards an appropriate activity. In other cases, children approached the magnetism station and started engaging (i.e., picking up materials) without any prompting from TCs. Children visiting the magnetism station could start and end their investigations at varied points.

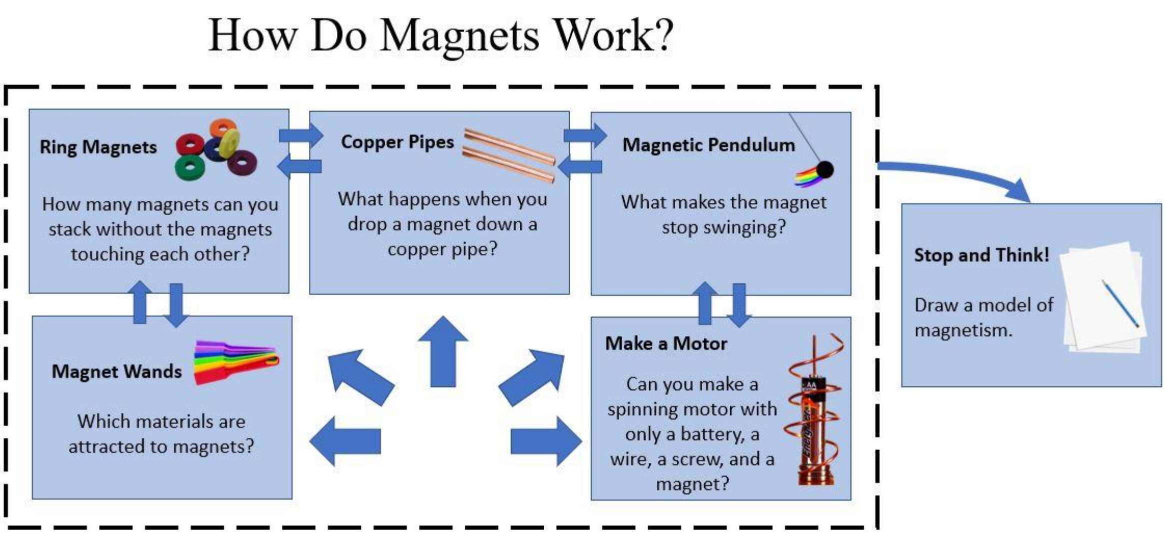


Figure 47. Multiple pathways available to children at the magnetism station.

One outcome vs. many outcomes. Another distinction was in the expected outcomes for each station. The slime station only had one outcome—to make slime. All students started at one end of the factory line, working through the clearly defined steps, and came out the other side with the same version of slime, bar color and sparkle. There was not much room for children to creatively explore or customize their slime due to the station design.

The magnetism station, however, had many possible outcomes. Rather than a tangible product (like slime), the magnetism station's expected outcome was conceptual understanding and model building. Children worked through different activities to further their own understanding of magnetic interactions. The activities were designed to progressively complexify their thinking over time. The more activities a child engaged in, the more opportunities they had to experience magnetism in varied contexts, helping them refine their mental models through increased interaction. Further, when a child seemingly reached an end point, or was unable to further explain or justify their thinking, children were often prompted to visit the “Stop and Think” area of the station. The magnetism station did not have one specified learning outcome. Rather, the station was designed to support many different outcomes.

Doing vs. reflecting. A final important distinction between the two stations was the presence (or absence) of a designated spot to stop and reflect. At the slime station, children made slime, possibly answered a question or two about states of matter, and left the station. There was no designated space to stop and reflect on the process of making slime, end product, or conceptual understanding related to states of matter.

Unlike the slime station, the magnetism station did have an intentional and designated spot to stop and think. The “Stop and Think” section had blank paper and writing utensils for children to use to draw their mental models of magnetism. Children were prompted to draw and explain something they observed at the magnetism station. See Figures 48 and 49 for sample drawings collected from children at the Maker Faire. In Figure 48, a kindergarten student drew the ring magnet activity. Note there are several circular magnets in this drawing, seemingly being attracted. The writing indicates that this child noticed that magnets have one “stiq side” and a “no stiq side,” (or, in other words, a sticky and non-sticky side). Figure 49 shows a drawing completed by a 4th grade student after investigating the magnetic pendulum activity. Without a designated space to stop and reflect, these children would probably not have created these drawings. However, the station allowed for this opportunity, which revealed important information about children’s thinking to Ms. Maggie and her group members.

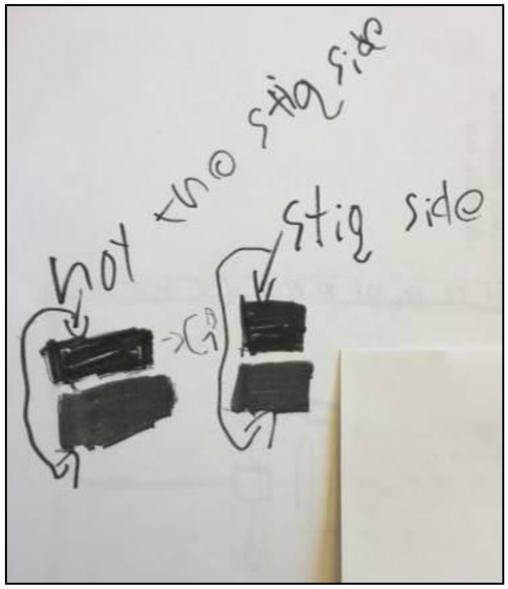


Figure 48. A kindergarten student's model of magnetism (age 6).

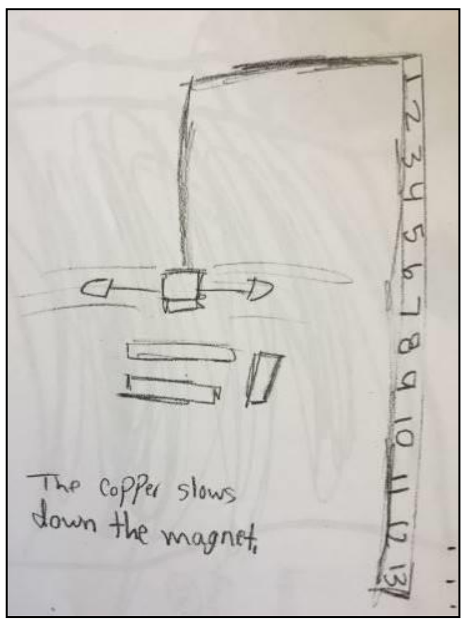


Figure 49. A fourth-grade student's model of eddy currents (age 10).

Differences in facilitation. This section describes differences in facilitation techniques used by Ms. Sarah and Ms. Maggie during the Maker Faire at their respective stations (see Figure 50). First, I present a quantitative analysis of the facilitation strategies. I then present a qualitative analysis to identify themes. To aid in comparison, the values shown in Figure 50 are presented as percentages of overall facilitation techniques used during the Maker Faire event by Ms. Sarah and Ms. Maggie, rather than frequency counts, to help account for the variation in how many children visited each station.

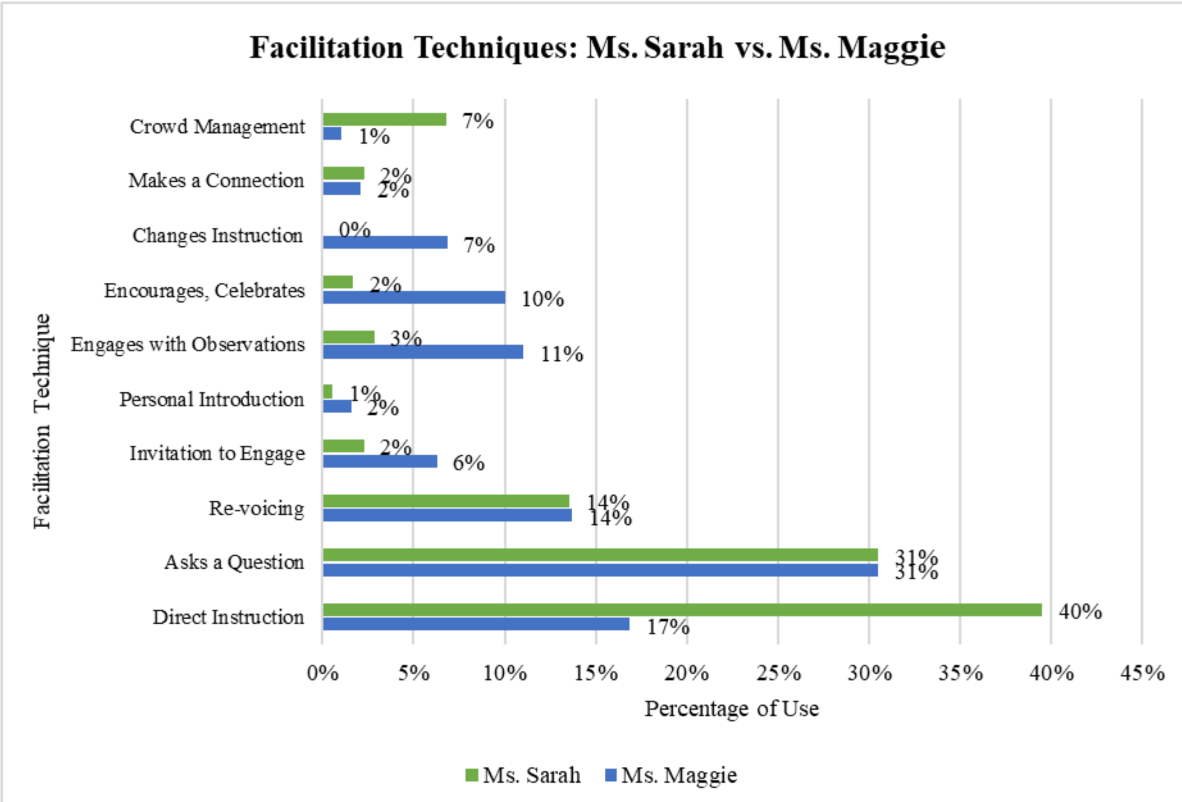


Figure 50. Facilitation techniques by TC, Ms. Sarah versus Ms. Maggie.

As shown above, there were differences between Ms. Sarah and Ms. Maggie's facilitation at the Maker Faire. Most noticeably, Ms. Sarah provided more direct instruction (40%) than Ms. Maggie (17%). Ms. Sarah also engaged in more crowd management (7%) than Ms. Maggie (1%). In contrast, Ms. Maggie offered more invitations to engage with her station (6%) as well as explicit encouragements and celebrations (10%) than Ms. Sarah did (2% and 2%, respectively). Ms. Maggie also engaged with more observations and data (11%) and changed her instruction based on children's ideas (7%) more often than Ms. Sarah (3% and 0%, respectively). Both TCs asked similar amounts of questions (31%), as well as re-voiced children's responses (14%) and made connections (2%) at the same rate. These differences in facilitation techniques impacted how the children engaged in the activities. Following, three themes are shared that encapsulate the major differences in facilitation that seemed to impact children's engagement with the stations.

Greeting children with an instruction vs. an invitation. One notable difference in facilitation between the stations was connected to how the TCs initially engaged children at their station. Recall that Ms. Sarah often greeted children who walked up the slime station with, "Grab a bowl," before instructing them about each of the sequential steps to follow thereafter. There were few instances of explicit invitations or personal introductions. Direct instruction was her primary method of communicating with children. Further, it is important to note that her instructions were often stated in a manner that would not allow a child to easily say "no." In most cases, when a teacher gives an explicit instruction to children, they usually follow (as is the norm in traditional, teacher-centered classrooms). If she had phrased her greetings as invitations (rather than instructions), children may have approached the station differently.

In contrast, Ms. Maggie offered children more explicit invitations to engage with her station. It was not uncommon for Ms. Maggie to ask a child, "Do you want to visit my magnetism station?" In these cases, Ms. Maggie asked and waited for the child's response before engaging with her. The way in which Ms. Maggie phrased these invitations provided the children an opportunity to say "no," honoring their individual choices and interests. For an example, recall the vignette at the beginning of the magnetism chapter featuring two brothers, Evan and Max. Evan was a sixth-grade student in Ms. Maggie's student-teaching classroom. After personally introducing herself to Evan's family, Ms. Maggie invited Evan and Max to engage with her station by asking, "Do you want to play here?" This invitation was worded as a question, not a command. In this example, Evan and Max choose to engage with the station by responding, “Yes.” However, there was another instance observed of a young child saying “no” to an invitation at the magnetism station. A young boy was asked if he wanted to “play” or “have the teacher show him something;” he responded “Play.” This allowed him to continue engaging with the station on his terms (tinkering with magnetic materials) before eventually engaging with the TCs to signal he was ready to “have her show [him] something.” This small difference in facilitation seemingly allowed children to approach the magnetism station on their terms more often, rather than simply following instructions from a TC.

Closed-ended vs. open-ended questions. The other major distinction between Ms. Maggie and Ms. Sarah’s facilitation is not immediately evident when looking at Figure 52. Both TCs asked questions of children at the same rate (representing 31% of their total facilitation techniques). However, a qualitative analysis of the questions asked revealed important differences.

Ms. Sarah asked more close-ended questions connected to material usage. Recall that nearly 50% of her questions were related to materials, 33% were connected to the process of making slime, and only 20% related directly to the conceptual learning goals of the station (see Table 13). The most common questions asked by Ms. Sarah were some variation of “What color dye would you like: Red, green, yellow, or blue?” and “What color glitter would you like: Gold or silver?” Both questions were closed (in that there were a limited amount of options a child could select between) and connected to procedural steps (rather than conceptual understanding).

In contrast, Ms. Maggie asked more open-ended questions connected to observations and data. Recall that nearly 75% of her questions were connected to content (see Table 23).

In 14% of these instances, Ms. Maggie asked a child to make a prediction before investigating; in the remaining 60% of these questions, Ms. Maggie asked children to construct explanations to describe results after an investigation. In both cases, though, the questions Ms. Maggie asked were connected to conceptual learning goals of the station. For example, it was common for Ms. Maggie to ask questions, such as "What did you notice?" or "What do you think is happening?", to elicit children's ideas about the phenomena under investigation. The open-ended, conceptual nature of Ms. Maggie's questions seemingly contributed to the increased levels of conceptual understanding displayed among children visiting the magnetism station. In contrast, children at the slime station were asked more procedural questions, possibly contributing to less indicators of conceptual understanding displayed.

Limited vs. large repertoire of facilitation techniques. The final notable distinction between Ms. Maggie and Ms. Sarah's facilitation was connected to the variety of techniques used. Ms. Sarah used a limited repertoire of facilitation techniques throughout the event. She primarily relied on direct instruction (40%), asking close-ended questions (~30%), re-voicing responses (14%), and crowd management (7%). Ms. Sarah most often provided direct instructions as greetings and prompts to move children along in the process of making slime. Similarly, she relied on close-ended questions about materials to ensure children were following the instructions for the station and frequently re-voiced children's responses back to them, as if confirming she heard them correctly. Finally, Ms. Sarah also relied on crowd management techniques throughout the event to move large groups of visitors down the factory line when certain areas were congested.

In contrast, Ms. Maggie used more variety in her facilitation techniques than Ms. Sarah. The facilitation technique she relied on most often was asking children open-ended questions (~30%). She supplemented this technique with similar amounts of direct instruction (17%) and re-voicing of children's responses (14%). Ms. Maggie also frequently engaged with observations (11%), encouraged and celebrated with children (10%), changed her instruction based on children's ideas (7%), and explicitly invited children to engage with her station (6%). She displayed fewer instances of crowd management (1%), making connections to outside experiences (2%), and personally introducing herself to visitors (2%). Ms. Maggie's large repertoire of facilitation techniques seemingly allowed her to interact more readily with a diverse group of children at the School Maker Faire. She frequently began interactions with open-ended questions about magnets to elicit children's initial conceptions before suggesting certain activities or introducing an interesting phenomenon for investigation. In her follow-up exchanges with children, Ms. Maggie frequently engaged with observations or data to push a children's thinking or explanation, as well as encouraged risk-taking and acknowledged moments of frustration. Finally, Ms. Maggie often changed her instruction based on children's ideas by introducing new materials or interesting questions and investigations.

Chapter VIII: Discussion

This study investigated how the design and facilitation of an activity impacted opportunities for children's learning in the context of a Maker Faire. The preservice elementary school teachers worked in small groups to design an activity to engage children in an *NGSS*-aligned learning experience. They facilitated their activities at a School Maker Faire as the culminating assignment for their Science Methods course. A detailed video analysis of the activity design, preservice teachers' facilitation, and indicators of children's learning revealed that both the design and facilitation were impactful factors that influenced what children were able to do, and learn, at each of the stations studied.

Ms. Sarah's slime station was designed for children to make slime and articulate the differences between states of matter (namely a liquid and a solid). During the event, Ms. Sarah relied on direct instruction as her primary method of facilitation. She frequently greeted children with an instruction (i.e., "Grab a bowl") and prompted them to move down the factory-style line, following the pre-defined steps. Occasionally, she asked questions to elicit where children were in the process of making slime (e.g., "Do you have water in there?"). More often, she asked questions related to material distribution (e.g., "Do you want gold or silver glitter?"). Children who visited the slime station showed the most indicators for the learning dimension of *initiative and intentionality.* They frequently took initiative by (a) asking questions to ensure they were following the correct steps (e.g., "Do I pour all the water in?"), or (b) requesting materials (e.g., "I think I need more liquid starch?").

Ms. Maggie's magnetism station was designed for children to tinker with various materials, observe evocative phenomena (e.g., eddy currents), test initial hypotheses, and develop models of magnetism. During the event, Ms. Maggie used a diverse range of facilitation techniques. She asked questions to elicit children's (a) initial ideas about magnetism before engaging with the activities (e.g., "What do know about magnets?"), (b) predictions about investigations (e.g., "What do you think will happen if we drop the magnet down this copper pipe?"), or (c) observations after an investigation (e.g., "What did you notice?"). Ms. Maggie only offered direct instruction when reviewing materials and setups for investigations. Further, she made more connections to outside experiences, encouraged risk-taking and experimentation, and acknowledged moments of frustration. Moreover, Ms. Maggie frequently changed her instruction based on a child's idea or question by introducing new materials and activities.

Children who visited the magnetism station showed significantly more indicators of learning than children who visited the slime station. Bringing together the findings about children's learning, differences in facilitation, and differences in activity design, the two stations exemplify dichotomies related to education that are also identified in the literature that guided this study.

Minds On vs. Hands On

In her keynote address at the 2016 FabLearn conference Edith Ackermann asked, "How might we create a culture where being quiet, observant, thoughtful, and contemplative strikes a balance with being a doer, entrepreneur, mover, and shaker?" In her speech, Ackermann praised the Maker Movement for revitalizing student-centered approaches to learning that involved authentic projects and tools. However, she cautioned educators and scholars from equating "doing" to "learning." Simply because an activity affords the opportunity to get one's hands on materials does not guarantee that learning follows. Rather, learning occurs when there is a balance between doing and reflecting, or as Ackermann (2001) described: a "cognitive dance" between "dwelling in" and "stepping back" (p. 10).

Learners should have opportunities to *dwell in* activities, investigations, and materials, but they should also have opportunities to *step back* to evaluate one's own process, understanding, and next steps. Other scholars have referred to this divide as "hands on" versus "minds on" (Carin, 1997). The slime and magnetism stations epitomize this distinction.

The slime station was *hands on, minds off*. The children were able to get their hands dirty, quite literally, but displayed little evidence of learning. Recall the TCs required the children to mix their slime with their hands. Most children appeared to enjoy the tangible, sensational nature of mixing slime. However, as evidenced by the analysis of learning, there was little conceptual understanding, problem solving, or critical thinking detected at the station. The slime station allowed children to get their hands on slime, but failed to turn their minds on about different states of matter.

In contrast, the magnetism station was *hands on* and *minds on.* Children were able to get their hands on various materials. Recall they sorted objects using a magnet wand, made ring magnets hover, dropped magnets down copper pipes and swung pendulums. Alongside the TCs, they were supported in using these materials to investigate magnetic phenomena. Unlike the slime station, however, children also had opportunities to turn their minds on. Most importantly, the TCs provided a designated space to "Stop and Think." They encouraged children who visited this station to draw models of magnetism. Further, TCs at the magnetism station asked more open-ended questions, attended to observations and data, made connections between investigations at the station, encouraged risk-taking and experimentation, celebrated moments of excitement, and acknowledged moments of frustration. The station's design and facilitation supported children in getting their hands on *and* minds on.

Expansive vs. Confined "Rooms" for Inquiry

Another important distinction between the design of the stations was connected to Resnick and Silverman's (2005) metaphor of a room representing cognitive barriers and opportunities when he described Logo, a programming language for children:

> *[It] is often described as having a low floor and high ceiling: it is easy for novices to get started (low floor) and possible for experts to work on increasingly sophisticated projects (high ceiling) …We have put…emphasis on what might be called 'wide walls.' That is, we have tried to design technologies that support and suggest a wide range of different explorations* (p. 118).

Resnick and Silverman (2005) noted that technologies should have "low floors" that reduce cognitive barriers to allow novices without much prior experience to get started quickly. Similarly, there should be "high ceilings" that allow learners to complexify their thinking over time. Moreover, there should be "wide walls" that support different types of investigations, purposes, and interests. While their recommendations were for designing *technologies*, they also help explain the differences observed between the design of *activities* at the magnetism and slime stations.

The slime station can be compared to a *confined room*. That is, most children's experience at this station was the same. There was a "low floor" for entry (anybody could easily get started), but, as facilitated, the ceilings were too low, and the walls were restricting. Children at the slime station were prompted to move down the factory line, following pre-defined steps, before eventually creating slime. The activity was intentionally designed so that children could not make mistakes along the way. TCs were positioned at every step to ensure children would know what to do. At the end of the factory line, all children were guided to create the TC's anticipated version of slime. Except for customizing the appearance of the slime by adding food dye and glitter, all students were expected to leave the station with the same product. There were few opportunities for children to complexify their thinking (low ceilings) and scant ways to diversify the exploration (narrow walls). In other words, the slime station confined the cognitive movements a child could make.

In contrast, the magnetism station can be compared to an *expansive room.* The station was intentionally designed in a way that afforded many possible pathways for learners. Recall the station featured five mini-activities that were designed to allow for choice and differentiation. For instance, consider the magnet sorting activity in which children sorted objects based on magnetic properties. Multiple times throughout the event, children were seen on camera playing with this activity, unprompted by the TCs. In this sense, the station had a “low floor” in that learners could easily get started. Perhaps more importantly though, the station had a “high ceiling,” in that learners could participate in increasing complex activities to deepen their understanding. Consider the homopolar motor activity which brought in the concept of electricity alongside magnetism, or the eddy current activity which featured phenomena above the *NGSS* performance expectations for elementary school students (“high ceiling”). Finally, the station had “wide walls” in that each child’s exploration was different. Ms. Maggie and her group members did not expect that every child who visited their station would engage in every possible activity. Rather, the station was designed for children to ask questions and test their initial understandings of magnetism by tinkering with various materials in different contexts. Due to the nature of this design, children left the station with different ideas based on their initial conceptions, interests, and unique experiences at the station. In other words, the magnetism station was an expansive room. It afforded low floors, high ceilings, and wide walls.

Learner vs. Teacher-Centered

The final distinction between the stations is captured in the following quote by progressive educator, John Dewey (1902):

> *The child is the starting point, the center, and the end. His development, his growth is the ideal. It alone furnishes the standard… Not knowledge of information, but self-realization, is the goal."* (p. 13).

More than one hundred years ago, Dewey (1902) advocated for using the child as "the starting point, the center, and the end" of all education experiences (p. 13). For Dewey, a child's innate interests and capacities were considered the driving force of educational experiences. Self-realization was the goal of education, rather than the accumulation of facts and information (Dewey, 1938). Dewey contrasted this progressive approach to education with traditional approaches with adults artificially segregating disciplines into areas of study for children, emphasizing decontextualized, factual recall. This difference—apparent in the magnetism versus slime station—might also be referred to as "learner-centered" versus "teacher-centered."

The slime station was *teacher-centered*. It was nearly impossible for a child to start making slime without a TC's help. Recall the vignette at the beginning of the Slime Chapter that featured Lily making blue, sparkly slime. Lily and her mother had to wait for an acknowledgment from Ms. Sarah to start at the station. Further, the TCs remained in control of the materials at the station. They instructed the children on what to add, how much to add, and in what order. TCs assessed children's learning by asking, "Do you think slime is a solid, liquid, or a gas?" If a child concluded, "Somewhere in the middle" and was able to justify his or her response with some version of, "Liquids take the shape of their container, but solids do not," (a typical definition provided in elementary school and memorized by many students), the TCs seemed content that learning had occurred.

The teacher-centered nature of the slime station impacted how children engaged with the station (and the resulting indicators of learning observed). The dimension of learning with the highest indicators for the slime station was *initiative and intentionality*. However, a qualitative analysis of how children demonstrated initiative and intentionality is important. Most instances involved children asking questions of the TCs to ensure they were following the correct procedures. For an example, recall Billy, who asked the TCs four consecutive questions related to procedures (e.g., "Do I pour all of the water in?"). While this was an example of a child taking initiative, the initiative was not directed towards investigating some phenomenon of interest; rather, it was to confirm that he was doing what the TCs requested. This type of initiative is not enough if the goal of learning is to create independent, problem-solvers capable of innovating solutions for the world's most pressing problems.

The magnetism station, however, was *learner-centered*. There was no clearly defined starting point for the station. Instead, the child was used as the "starting point" (Dewey, 1902, p. 13). Children engaged with different initial activities at the magnetism station based on their past experiences, age, and interest. For example, a toddler might have only played with the magnet wand activity, but older children were able to progress through increasingly complex investigations. There was not a rigid progression of activities pre-identified by the TCs, rather the TCs were responsive to the children who visited their station.

Further, the magnetism station was learner-centered as evidenced by the way TCs interacted with children. TCs primarily acted as facilitators at the station. They set the stage for investigations, asked children to share predictions, helped demonstrate phenomena using evocative materials, pressed children to describe what they noticed, and supported children in the development of models to make sense of magnetic interactions. It was common for TCs at the magnetism station to change their instruction based on a child's observation or question. There was also less overall direct instruction used at this station.

The learner-centered nature of the magnetism station seemingly allowed for more observable indicators of learning among children. The most notably dimension of learning was the high levels of *conceptual understanding* observed. Perhaps an unsurprising finding in hindsight, TCs at the magnetism station asked children to continuously make predictions and describe results which allowed them to construct verbal explanations more often than was possible at the slime station. Similarly, children at the magnetism station displayed more indicators of learning for the dimension of *creativity and self-expression*. More children spent time playfully exploring (recall that children stayed three minutes longer, on average, at the magnetism station compared to the slime station). Additionally, children were supported in disagreeing with others' ideas through scaffolded conversations (Ms. Maggie and her group members often ensured each child shared a prediction before starting an investigation). Overall, the learner-centered nature of the magnetism station supported children in developing and demonstrating more indicators of learning than the slime station.

Limitations and Future Directions

There are limitations to this study. First, this study only investigated the facilitation of two activities at a Maker Faire as designed by two small groups of preservice teachers. These results are not generalizable to all preservice teachers, nor are they generalizable to all activities hosted at an informal science event, such as a Maker Faire. More research of a similar nature is needed to investigate other activities in similar contexts to further validate the findings presented here.

Second, there are limitations due to the point-of-view cameras. Because only Ms. Sarah and Ms. Maggie wore the cameras, their group members were not captured on film for equal amounts of time. This made it difficult to compare within groups. Similarly, the point-of-view cameras made it difficult to see what was occurring simultaneously. For instance, if Ms. Maggie was facilitating an activity with a child independently, the camera did not capture her group members who were simultaneously facilitating activities with different children. Due to this, stationary cameras—in addition to the point-of-view cameras—should be used. Further, each teacher should wear an external microphone to better capture verbal facilitation.

Another limitation was due to the informal nature of the Maker Faire. No additional data was collected on the children who visited each station. Unless explicitly stated in the video, demographic information (such as age, grade level, language proficiency levels, or previous experiences with science and engineering) was unknown. This made it difficult to compare children directly. The same population of children had the opportunity to visit all the activities, and so we can assume the demographics were similar across the stations, but it is possible this was not the case. If, for example, older children were more likely than younger children to visit one of the stations but not the other, then the indicators of learning might vary based on these demographic categories (i.e., problem solving and critical thinking might look different for a kindergarten student versus a sixth-grade student). Future work should collect baseline data from the children (with a parent's consent).

Similarly, no formalized assessment was given to measure students' conceptual learning gains by participating in each station. There was no pre- or post-test. Rather, learning was conceptualized from a situated perspective, which emphasizes engaging in authentic practices in context. The learning dimensions coded for, however, were not the same practices specified in the *NGSS*. In other words, children's learning was not analyzed in alignment with the *NGSS*. This is a future direction for research.

A final limitation to this study was the focus on *preservice* teachers. These participants were still novices, learning how to teach. It would be interesting to analyze the design and facilitation of activities hosted by veteran teachers with more years of experience. Similarly, the facilitation techniques coded for in this study were not taught to the preservice teachers before the School Maker Faire event. If this material had been covered in their Science Methods course, for example, the preservice teachers may have used more of the techniques. This is an area of future research.

Implications

This work has implications for educators seeking to design and facilitate interactive learning experiences, as well as implications for teacher educators and researchers. All are discussed in the following subsections.

Educators. First, the way in which activities are designed to support learning is consequential. Simply because an activity allows a learner to get their "hands on" materials does not guarantee that learning follows. Instead, activities designed as *expansive rooms* have "low floors" that allow learners to get started easily, "high ceilings" to complexify their thinking over time, and "wide walls" to support multiple ways of engaging. If an activity only allows for one product (e.g., slime) or one correct explanation (e.g., "Liquids take the shape of their container, but solids do not."), an activity is not learner-centered in its nature. It fails to provide choices to students. These choices matter. Each student brings with them a wide array of past experiences, interests, and goals. An activity should provide opportunities for diverse groups of children to engage based on their terms.

Second, the design of an activity constrains the types of facilitation techniques available. For instance, the procedural nature of the slime station led to more direct instruction and fewer open-ended questions. This is not a criticism of Ms. Sarah as much as it is a criticism of the slime activity design. Because there was only one product in mind, TCs ensured they guided children to the correct endpoint; less diverse facilitation techniques were required. In contrast, because the magnetism station was designed in a learner-centered manner that allowed for multiple pathways based on children's ideas, the resulting facilitation techniques were more diverse. Ms. Maggie asked more open-ended questions to elicit children's thinking before engaging in direct instruction. Further, because each child's experience at the magnetism station was different, Ms. Maggie was forced to adapt her facilitation to the child. If a child vocalized her frustration, Ms. Maggie acknowledged it. If a child took control of the materials to investigate a question he or she had, Ms. Maggie encouraged risk-taking and experimentation. In these instances, Ms. Maggie's facilitation was in response to what the child did. This led to more observable indicators of learning.

Teacher educators. In addition to the implications shared above for teachers, there are other implications for teacher educators. First, like other research has indicated (e.g., Hammerness et al., 2005) previous experience with a subject matter impacts how a teacher will engage with and teach that subject. For instance, Ms. Sarah intentionally positioned herself out of having to explain science content during the Maker Faire. While the Science Methods course instructor intended to lower the stakes of this assignment by allowing TCs to work in groups, the consequence was Ms. Sarah did not improve her science content knowledge. Instead, she opted to focus on management and organization (something Ms. Sarah and her group members considered to be her strengths). This was not a particularly surprising finding. However, it does signal a need for teacher educators to purposefully structure assignments and projects to ensure preservice teachers get practice in areas they need to further develop.

Moreover, this work implies that teacher educators may need to *confine the room more* when designing learning experiences for preservice teachers to ensure they can practice designing and facilitating interactive, student-centered activities. In this study, the Science Methods course instructor used an expansive room model, allowing preservice teachers to select any activity to facilitate at the Maker Faire. It may have been more effective if the course instructor had provided additional guidance or placed purposeful restrictions on the types of activities preservice teachers could choose. This may have resulted in the preservice teachers gaining increased exposure to activity designs that are better aligned with the goals of educative making. It is important to note that neither station, slime nor magnetism, was a particularly great example of an educative making activity. While the slime station allowed for the creation of a physical artifact, the magnetism station did not (unless one considers the physical models that students drew to make sense of observed phenomenon as artifacts). Further, while the magnetism station allowed for individual agency and learning pathways, the slime station only allowed visitors to make the same product. More work is needed to establish a common understanding of what counts as an educative making activity.

Finally, informal science events are particularly fruitful contexts for preservice teachers to gain experience facilitating activities for a diverse group of learners. At both stations, Ms. Sarah and Ms. Maggie engaged with leaners of varied ages, backgrounds, and prior experiences. They had to continuously adjust their facilitation to support different types of learners. For example, at one point, Ms. Maggie was facilitating an activity for a group comprised of two students from upper elementary grades (4-6), two students from lower elementary grades (K-3), and some of their parents. During these types of interactions, preservice teachers have opportunities to complexify their understanding of how different types of learners engage with the same activity, developing their own learning progression. There is some evidence to suggest that both Ms. Sarah and Ms. Maggie complexified their facilitation *over time*; however, the data was not analyzed with this research question in mind, thus it is an area of future research.

Researchers. This study contributes to the emergent research body investigating how educative making can support learning. It tests Bevan et al.'s (2017) dimensions of learning in a new context, with different activities, teachers, and children. As evidenced by this study, there are areas of Bevan et al.'s (2017) framework that might need revision. For instance, the indicator of learning *expressing emotion* might better align with the dimension of *social and emotional engagement* rather than *creativity and self-expression*. Similarly, the indicator *asking questions* was problematic. Bevan et al.'s (2017) framework included asking questions under the dimension of *problem solving and critical thinking*, however, that did not align with the data analyzed in this study. Perhaps, due to the design of the slime activity, children asking questions to request materials seemed to better fit with the dimension of *initiative and intentionality*. More work is needed to further investigate and refine this framework to be useful across varied contexts.

Second, this study contributes to the research body investigating the use of point-of-view cameras to investigate teaching in action. Like other researchers using this methodology (e.g., Russ & Luna, 2013), point-of-view cameras offer rich data about a teacher's action in context. This methodology allowed me to carefully analyze the preservice teacher's facilitation moves and resulting indicators of children's learning, providing motivation for the continued use of this methodology. This study also generated limitations of this methodology (such as not capturing TCs co-facilitating at an event) and recommendations for future applications (such as having stationary cameras and requiring all teachers to wear external microphones for better audio quality).

Finally, this study reconceptualized the relationship between “in-school” and “out-of-school” learning for both K-12 students and preservice teachers. The School Maker Faire was a hybrid event. It featured preservice teachers facilitating *NGSS*-aligned activities in an informal setting. Children from their student-teaching classrooms attended the event on a weeknight on the university’s campus. The children had opportunities to explore science and engineering in engaging activities. The preservice teachers had opportunities to learn about children’s ideas related to science and engineering phenomena, and gained practice facilitating these activities many times over for new guests. This arrangement was mutually beneficial for all parties involved, serving as a model for other researchers and educators seeking to break down barriers between “in-school” and “out-of-school” learning. This shared similarities to Barron’s (2006) conceptualization of learning ecologies, which aim to better connect “in-school” and “out-of-school” learning to support individual’s development of interests and identities. In other words, individuals are always learning (not just when they are in classrooms), and educators and researchers should be intentional about how learning opportunities connect across boundaries. The School Maker Faire was an exceptional example of connecting “in-school” and “out-of-school” learning for both students and preservice teachers.

Conclusion

On the final day of Science Methods, Ms. Sarah and Ms. Maggie’s drew pictures of an effective science lesson. The differences between the drawings reflect larger distinctions between the slime and magnetism stations. In Ms. Sarah’s drawing, the teacher is the focus of the lesson. She is in the center of the room, in control of the materials, while the students are on the opposite side of the table. The teacher is saying, “Come be hands on and learn!” In Ms. Maggie’s drawing, however, *there is no teacher present.* Ms. Maggie drew a student, working with laboratory materials independently and thinking, “I know because I’ve done and see it myself.” Like the drawings, at the Maker Faire, the slime station was indeed hands on, but there was little evidence to suggest that students were explaining the “why” and “how” behind slime while, at the more learner-centered magnetism station, students made predictions, tested hypotheses, and revised their models of magnetism using evidence collected from investigations. The teacher’s role was that of a facilitator, rather than a direct guide.

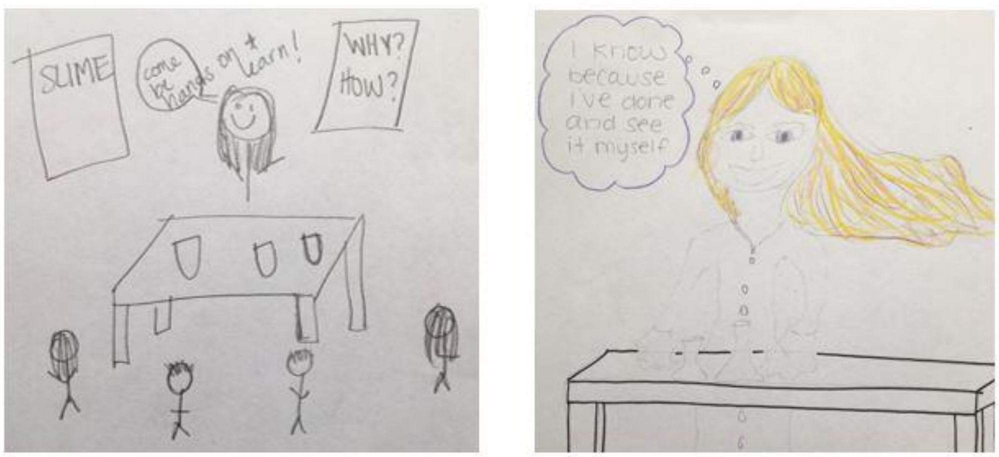


Figure 51. Drawings of effective science lessons, Ms. Sarah versus Ms. Maggie.

The distinctions between the slime and magnetism station represent a larger divide in education. They speak to the contrast between authoritative, transmission models of instruction—that are often enacted when mass, standardized assessments for accountability are prioritized—to student-centered, experiential learning that values the learner as an individual with their own ideas, questions, and aspirations. This study provided further evidence that children learn *more* when they are given the opportunity to explore and question the world around them, on their terms, rather than following prescribed steps from an adult, memorizing facts for eventual regurgitation. As noted by Dewey (1938),

> *What avail is it to win prescribed amounts of information about geography and history, to win ability to read or write, if in the process the individual loses his own soul…loses the ability to extract meaning from his future.* (p. 49)

Like Dewey, I believe that education should seek to tease out and foster children's innate interests, helping them make sense of who they are, what they want in life, and how they can begin to reach for it.

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Appendix A

Maker Faire Interview Protocol

Thank you for agreeing to be interviewed today! The purpose of this interview is to learn about your views of and experiences related to teaching and learning science and engineering connected to your enrollment in ED320S: Elementary Science Methods. Please try to be as candid and specific as possible.

The information from this interview will not affect your course grades, your teaching placements, or your standing in the Teacher Education Program. If there is a question you do not wish to answer, you can ask that it be skipped. If you later wish to revise an answer or to ask that an answer be deleted, you are free to do so as well.

We expect the interview to last about 30 minutes. Do I have your permission to begin recording the interview? [Turn on recorder]

Today is [Date] at [Time]. This is the initial interview with [Participant Initials] and the interviewer is [Interviewer Name].

Introduction (5 minutes):

First, I'd like to ask you a couple questions about your interest in teaching.

1) What are some reasons why you decided to become an elementary school teacher?

2) Where do you hope to teach after completing the program? Why?
    a. Grade(s)?
    b. Type of school – public, private, charter?
    c. Location?

Science Lesson (5 minutes):

3) On the first day of class, you were asked to draw an effective science lesson and describe what the students and teacher were doing. Here is your response. Tell me about your response.
    a. Would you add, delete, or change anything now? Explain your reasoning.

Maker Education (5-7 minutes):

These next few questions are about your ideas related to effective science and engineering teaching connected to making.

4) As you may have noticed, we have done a lot of making in ED 320.
   Reminder prompts: Shadow puppets, marshmallow tower, circuits with LEDs (valentine's cards, squishy circuits with playdough, makey makey), coding, robotics, etc.

Do you feel these activities helped **you** learn? Why or why not?
Follow-up prompts: Do you think these activities helped you learn science? Engineering?

5) Do you think having **kids** design or create things helps them learn about **science**? Why or why not?

6) Do you think having **kids** design or create things helps them learn about **engineering**? Why or why not?

<u>Maker Faire (10 minutes):</u>

The next set of questions is about the upcoming Maker Faire.

7) What activity are you facilitating at the Maker Faire? Please describe.

8) How do you currently feel about facilitating that activity at the Maker Faire, in general? Explain why. (e.g., excited, nervous, indifferent, etc.?)
    a. *Follow-ups*: What do you imagine will be **enjoyable or fun** about the Maker Faire?
    b. What do you imagine will be **challenging** about the Maker Faire?

9) What do you hope students gain by participating in your Maker Faire activity?
    a. *Follow-ups*: Are there any specific **NGSS science/engineering practices** you expect students to learn? [Show practices]
    b. Is there specific science or engineering **core ideas** you expect students to learn? [Show DCIs]
    c. Are there specific **crosscutting concepts** you expect students to learn? [Show concepts]
    d. Are there any **non-cognitive skills** you hope students gain?
        i. Perseverance, grit, confidence, a greater interest in STEM, etc.?